PB-223 162

PNEUMO-SLURRY PIPELINE COLLECTION AND REMOVAL OF MUNICIPAL SOLID WASTE

I. Zandi

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Prepared for:

Environmental Protection Agency

September 1973

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5285 Port Royal Road, Springfield Va. 22151

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA-670/2-73-072	2.	3. Recipient's Accession No. PB-223 162

4. Title and Subtitle
PNEUMO-SLURRY PIPELINE COLLECTION AND
REMOVAL OF MUNICIPAL SOLID WASTE

5. Report Date
1973-issuing date

6.

7. Author(s)
I. Zandi

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
University of Pennsylvania
The Towne School of Civil and Mechanical Engineering
Philadelphia, Pennsylvania 19104

10. Project/Task/Work Unit No.

11. Contract/Grant No.
EP-00259

12. Sponsoring Organization Name and Address
U.S. Environmental Protection Agency
National Environmental Research Center
Office of Research & Development
Cincinnati, Ohio 45268

13. Type of Report & Period Covered
Final

14.

15. Supplementary Notes

16. Abstracts

This study represents a compilation of research performed at the University of Pennsylvania and summarizes a series of papers, some previously published in various journals. The report concerns itself with the subject areas of: pipeline collection and transportation of solid wastes; pneumo-slurry system of collection, removal, and transport of solid waste; size reduction of solid waste using a hammerhill crusher; flow properties of solid waste slurries; and cost-benefit analysis of pneumo-slurry systems.

17. Key Words and Document Analysis. 17a. Descriptors

*Pipeline transportation, *Refuse disposal, Slurries, Crushers, Cost analysis, *Fluid mechanics, Effluents, Reclamation, Grinding mills

17b. Identifiers/Open-Ended Terms

University of Pennsylvania, Pipeline collection, *Pneumo-slurry, Hammerhill, Resource recovery, Waste grinding system, Municipal solid waste

17c. COSATI Field/Group 13B

18. Availability Statement Release to public ia	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages ~~128~~ 126
	20. Security Class (This Page UNCLASSIFIED	22. Price $7.25

FORM NTIS-35 (REV. 3-72)

THIS FORM MAY BE REPRODUCED

USCOMM-DC 14952-P72

EPA-670/2-73-072
September 1973

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By

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Grant No. EP-00259
Program Element No. 1D2063

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Prepared for
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

In an attempt to solve the problems that arise in solid waste management, this report, published by the National Environmental Research Center - Cincinnati, represents a compilation of research performed at the University of Pennsylvania concerned with pneumo-slurry collection, removal, and transportation of solid wastes.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center - Cincinnati

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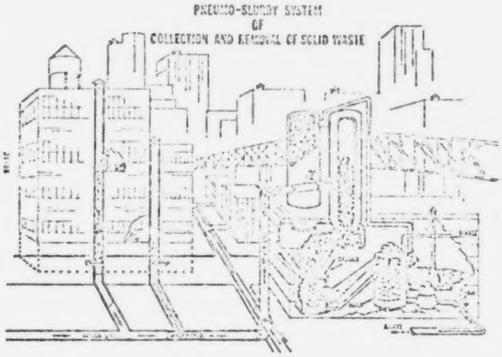
"Memory Holes"

Fully Automated System of Solid Waste Collection and Transport

by

Iraj Zandi[*]



PNEUMO-SLURRY SYSTEM
OF
COLLECTION AND REMOVAL OF SOLID WASTE

I. Purpose

> "IN THE WALLS of the cubicle were three orifices. To the right for written messages; to the left, a larger one for newspapers; and in the side wall, within easy reach of Winston's arm, a large oblong slit protected by a wire grating. This last was for the disposal of waste paper. Similar slits existed in thousands or tens of thousands throughout the building, not only in every room but at short intervals in every corridor. For some reason they were nicknamed memory holes. When one knew that any document was due for destruction, or even when one saw a scrap of waste paper lying about, it was an automatic action to lift the flap of the nearest memory hole and drop it in, where upon it would be whirled away on a current of warm air to the enormous furnaces which were hidden somewhere in the recesses of the building."

And so wrote George Orwell in his political novel entitled "1984".(1) Should Mr. Orwell be alive today and could visit Sundeberg, a suburb of Stockholm, Sweden, indeed, he would be surprised to find that his prophetic concept of MEMORY HOLES is not any longer a part of a fiction story --- but it is a reality. In Sundeberg, the household solid waste of several thousand apartments is swept along in an air stream of about 90 feet per second in underground pipes to a waste incinerator 1.7 miles away. The heat generated in the incinerator is distributed to the apartments. Many similar systems are already under construction in various parts of the world.

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Orwell's world of "1984" is one in which eternal warfare is the price of bleak prosperity and in which the "party" keeps itself in power by complete control over man's action and thought. One should be thankful that not all of Mr. Orwell's prophecy came true. But the one which in a limited way is a reality now-- pipeline collection and transport of solid wastes-- is worthy of serious thought and examination. The present paper attempts to examine this concept.

II. Introduction

Management of solid waste involves a variety of activities. Its nature and characteristics can be more conveniently and efficiently discussed by reference to Figure 1,(2) where the flow of waste through various "control systems"* is shown. To understand the figure the reader should note that the circles signify some type of storage processes and refer to certain stages of waste, rectangles indicate control processes which for the most part are only susceptible to individual actions, and rounded rectangles imply the control processes sensitive to institutional control. Collection is to be interpreted in this paper as the process by which the waste is removed from the source to a vehicle for removal. Removal is meant to imply short-haul transport, normally using compactor-trucks (for junk cars other means are used). "Transport" refers to transfer operation when "transfer stations" are involved.*

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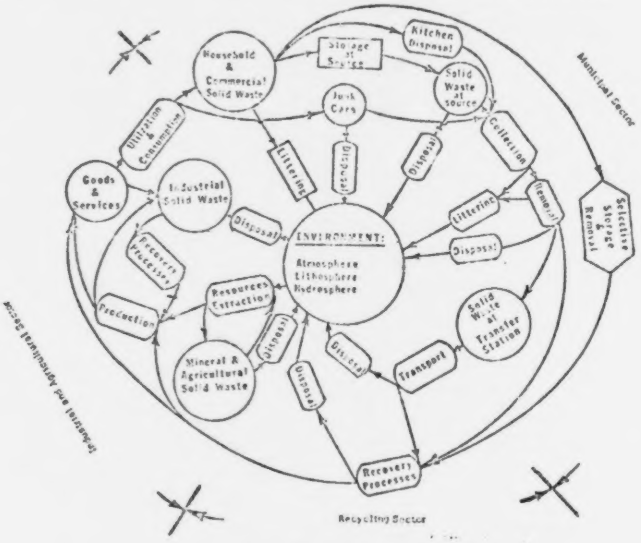
* The word control here implies potential rather than actual, i.e., the opportunity to exert control whether it is actually exerted or not.


Household & Commercial Solid Waste
Storage at Source
Kitchen Disposal
Solid Waste at source
Junk Cars
Municipal Sector
Utilization & Consumption
Goods & Services
Industrial Solid Waste
Littering
Disposal
Collection
Removal
Selective Storage & Removal
ENVIRONMENT:
Atmosphere
Lithosphere
Hydrosphere
Recovery Processes
Resources Extraction
Production
Mineral & Agricultural Solid Waste
Solid Waste at Transfer Station
Transport
Industrial and Agricultural Sector
Recycling Sector

Solid Waste Management System

Figure 1

There are a number of disadvantages inherent in the collection of solid waste and its removal to the point of disposal by truck. Obvious ones associated with storage at the source include unsightliness, fire hazard, and the harboring of flies, rats, and other vermin; those disadvantages associated with collection are the need for frequent collections, labor problems, effect on the health of the labor force, and the tremendous waste of human resources on an unproductive job. Associated with the removal of solid wastes to the points of disposal are such disadvantages as the effects on the transportation arteries of the cities, and the effect of snow on the collection procedure. Finally, truck transportation becomes more expensive as the distance of haulage to the point of disposal increases beyond a certain limit. This last consideration has forced cities to dispose of their waste close to the center of population, resulting in poor utilization of valuable land and severely restricting the disposal processes.

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* In the United States, 337,000 persons operating 272,000 vehicles have been collecting, transporting and disposing of in excess of 1 billion pounds (3) per day of municipal solid waste for an annual cost of 4.5 billion dollars (1968).

Obviously, the steady growth of cities, combined with the increased waste produced by an affluent society, will only intensify these unfavorable characteristics. No management miracles or mere refinement of present solid waste technology is capable of eliminating all these objectionable aspects. If their elimination is desired, a new technology must be developed. "Solid Pipeline"* may present such a technology.

It is a well-known fact of fluid mechanics that either liquids or gases, when flowing with high velocities, are capable of entrapping solid matters and carrying them along. This characteristic of flowing fluids has been long utilized in industry for transport of bulk solid matter,(4) and it could be employed for the purpose of automatic collection and removal of solid waste.

A fully automatic system of collection and removal should begin at each premise and terminate at the point or points of disposal, and should be such that it admits almost any type of waste. If the distance between points of generation and the point of disposal is short (1 or 2 miles) a pneumatic system (air is being used as the carrier)** could very well serve the purpose. No presizing is required when dimensions of the waste are less than 20 inches---this includes almost 98% of all household wastes.

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* "Solid Pipeline" is a term used to indicate a pipeline conveying bulk solids either in a flowing air or liquid.

** The Swedish system previously mentioned operates on this principle. In the ten years that the system has been in operation, no clogging has occurred.

When the haulage is more than a few miles, and/or the total volume of waste in the pipe at a single moment is excessive, the pneumatic system becomes impractical or uneconomical. Under these conditions, slurry pipeline becomes quite attractive. The slurry pipeline (water being used as carrier) becomes less expensive per ton mile as the haulage and volume increase. However, a slurry system requires presizing of materials. This requirement implies that for a total slurry system, a presizing unit is required at each point of generation. The presently available presizing units are too massive and too expensive to be installed in each building. Consequently, if the disposal point is far away from generation points neither system (pneumatic or slurry) alone would work. A combination plan has to be worked out. There are two alternatives:

1. A semi-automatic system, utilizing trucks to collect the solid waste of different neighborhoods and remove it to various small, centrally located points where the wastes would be crushed and mixed with a small percentage of sewage to produce slurry to be pumped over long distances for disposal. Of course, this system has many of the disadvantages associated with truck collection.
2. A pneumo-slurry system, where pneumatic pipelines would replace the truck collection of the previous alternative. This system produces a flexible scheme which is fully automatic, capable of long distance transport, and does not require a presizing unit at each building.

The pneumo-slurry system can potentially be incorporated into a total solid waste management system. Figure 2 exhibits one possible scheme where the pipeline is utilized as a reactor for treatment of solid waste during conveyance.

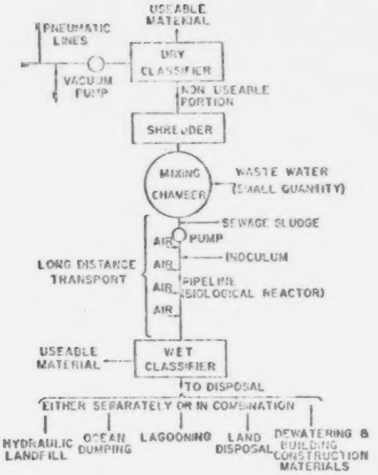

USEABLE MATERIAL
PNEUMATIC LINES
DRY CLASSIFIER
VACUUM PUMP
NON USEABLE PORTION
SHREDDER
MIXING CHAMBER
WASTE WATER (SMALL QUANTITY)
SEWAGE SLUDGE
AIR
PUMP
AIR
INOCULUM
LONG DISTANCE TRANSPORT
AIR
PIPELINE (BIOLOGICAL REACTOR)
AIR
USEABLE MATERIAL
WET CLASSIFIER
TO DISPOSAL
EITHER SEPARATELY OR IN COMBINATION
HYDRAULIC LANDFILL
OCEAN DUMPING
LAGOONING
LAND DISPOSAL
DEWATERING & BUILDING CONSTRUCTION MATERIALS

Fig. 2 - A possible system of collection and disposal of solid waste.

Whether pneumo-slurry system of collection, removal, and transport of solid waste becomes a viable alternative to the truck operation, depends upon the answers to four fundamental questions:

1. Is pneumo-slurry transport of solid waste technologically feasible?
2. How does pneumo-slurry system compare economically with the present truck collection and removal?
3. What method of treatment and disposal is best suited to this type of transport?
4. What governmental instrument is needed to bring about the change and what will be the sociological impact of the change?

The present chapter will discuss the first two questions, the third question is discussed elsewhere,(5) and the fourth one is yet to be studied.

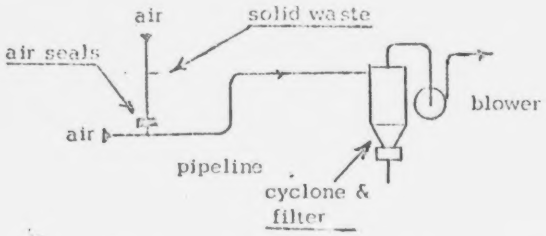
III. Is Pneumo-slurry transport of solid waste technologically feasible?

This question needs to be answered for two distinctly different systems: a) pneumatic collection and removal and b) slurry transport. As it was previously mentioned, pneumatic collection and removal of solid waste is practiced in a number of installations around the world. There is sufficient field experience and information available which indicate both feasibility and reliability of this mode of handling municipal solid waste. As far as slurry transport is concerned, sufficient laboratory data is available to permit the conclusion that it is indeed technologically feasible to transport slurries of solid waste, but, since there has been no field study as yet, the reliability of such system remains to be investigated.

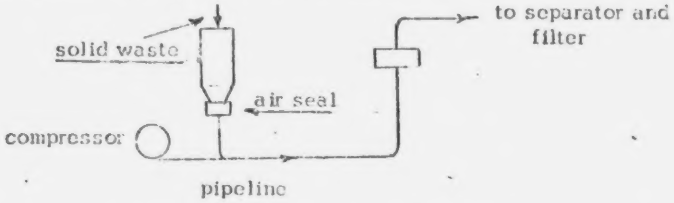
IIIA. Pneumatic collection and removal

There has been a steady growth of this mode of bulk transport since World War II. The plastics industry has provided impetus for the growth of pneumatic conveying systems. Systems which convey materials about 500 to 1,000 feet are more commonplace in the industry and systems about 5,000 feet long are becoming usual.(6)

There are two basic pneumatic systems feasible: 1)positive pressure conveying systems and 2) vacuum conveying systems. Figure 3 shows schematically these two variations. The vacuum system, where the air enters at the atmospheric pressure and entraps solid materials and conveys them toward the vacuum pump, is a preferred system where materials are to be collected from several points to a single destination. This is actually the system utilized in Sundeberg, Stockholm, to collect and remove solid waste from a series of apartment houses. In this system solid waste is collected and removed through pipes ranging in diameter between 21 and 24 inches due to a 1/2 atmospheric vacuum produced by five turbo-extractors, each driven by a 100 KW electric motor.(7)


air
solid waste
air seals
blower
air
pipeline
cyclone &
filter

3a- vacuum conveying system


to separator and
filter
solid waste
air seal
compressor
pipeline

3b- positive pressure conveying system

The design of a pneumatic solid waste pipeline includes the calculation of necessary power required to transfer the waste. This can be accomplished by the following equations:

$$P = P_a + P_m \qquad (1)$$

where P is total power requirement, P_a is the power losses due to the flowing air, and P_m is the power losses due to flow of material. P_a is comprised of collection losses P_{ac}; pipe losses P_{ap}; seperation losses P_{as} and filter losses, P_{af}, all in ft.lbs./min. Conduit power loss,

P_{ap}, may be calculated from the chart shown in figure 4. Minor losses P_{ac}, P_{as}, and P_{af} depend largely on the design of the system. Note that the chart in figure 4 yields the value of energy loss in inches of water vacuum and should be converted to ft.lbs./min. in order to be used in equation 1.* Collection losses are small and may be neglected. Separation and filter losses vary and depend on their design, and they are generally given by the manufacturer. It would be conservative if one assumes that total minor losses are equal to one foot of water.

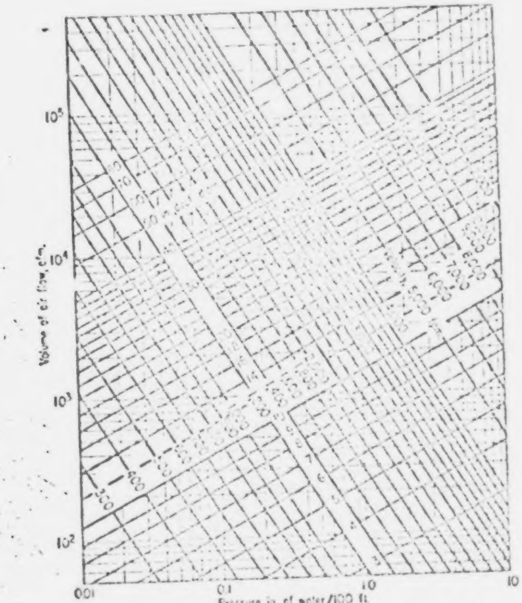


Figure 4 (taken from reference 8)

Material losses can be calculated by the following equation:

$$P_m = P_{m1} + P_{m2} + P_{m3} + P_{m4} \qquad (2)$$

where P_{m1} is the acceleration power required to initially propel solids at rest, P_{m2} is the power required to change the elevation if required by the design, P_{m3} is the power required to sustain the horizontal motion, and P_{m4} is the minor power losses because of bends in the system, all in ft.lbs./min. The following equations may be used for calculating these losses:

---

* h (in. of water) = P (ft.lbs./min.)/q(ft.^{3}/min.) (5.2) (7)
where q is the air flow rate and 5.2 is the conversion factor.

$$P_{m1} = MV^2/2g \tag{3}$$

$$P_{m2} = MH \tag{4}$$

$$P_{m3} = MLF \tag{5}$$

$$P_{m4} = (MV^2/gR)lF \tag{6}$$

where M is the quantity of solids to be conveyed in lbs./min., V is the mean velocity of conveying air in ft./min., H is the elevation change in ft., L is the horizontal transport distance, R is the radius of the bend, and l is the distance traveled in the bend, and F is a factor called by Fischer(8) a "finagle"factor. Experience in Sundeberg shows that mean air velocity of 80 to 90 ft/sec. would be sufficient to carry household solid waste. Therefore, at the present time, it is recommended that the mean air velocity for pneumatic conveyance be assumed between 80 to 90 ft/sec. As more experience will be gained it may be possible to reduce this velocity somewhat.

Fischer(8) recommends that for the bulk solids the factor F may be assumed to be the coefficient of friction between the material being conveyed and the material from which the duct is made. This coefficient can be calculated as the tangent of the angle of slide.* While it has been shown that the interpretation of F as the coefficient of friction for bulk solids yields satisfactory and duplicative results, its use for solid waste should be treated cautiously. This procedure may be used only as a rough estimate of power requirement. A large factor of safety is required to assure the proper functioning of the system.

---

* "The angle of slide"of a material is the angle with the horizontal of an inclined flat surface at which slope a quantity of material begins to slide downward over the surface. The material must slide over the flat surface and not over itself."(9) It is measured by placing a quantity of the material gently on a smooth horizontal plate made of the duct material and one edge of the plate is raised while the other edge is held stationary. The angle at the time of incipient motion is the angle of slide.

IIIB. Slurry transport

The transport of solid waste slurry involves two basic unit operations: 1) pre-sizing and 2) pipeline conveyance.

1. presizing - Pre-sizing the solid waste presents a difficult problem. The extreme heterogeneity of waste in regard to density, size and its other physical characteristics excludes the use of a single size-reduction process for effective and efficient pre-sizing operations. A preliminary investigation of available shredders indicated that: "It is the policy of most manufacturers of crushing equipment to carefully match the machine used to crush a particular material to the material being crushed, so that efficient crushing will result. Since refuse contains samples of all kinds of materials, few, if any, machines are available which will completely break up unsorted trash. The hammermill seems to be the crusher best adapted to the crushing of refuse. Because it combines shear, tension and compression in the fracturing process, it can break up a wide range of materials. It can also be designed to expel large dense ductile objects such as bolts and pipe fittings, thereby preventing destruction or jamming of the machine. It may be necessary to employ a two stage crushing process or to use a closed loop system in order to end up with a particle size which is small enough to be carried in a water slurry."(10) Information is presently available in two types of pre-sizing units, handling municipal solid waste: 1) a hammermill and 2) a combination of a Pulper

and a Gorator.* It is shown that both hammermill and Pulper-Gorator are capable of pre-sizing the raw solid waste. The hammermill, however, requires considerable maintenance. (See Appendix I and Appendix II.)

As a result of available information, it is possible to claim that size reduction of solid wastes, to render it suitable for pipe transport, is possible.(11) Although, it should also be added that a more efficient system has to be developed to ensure reliability and economy. Figure 5 shows solid waste before and after being processed in a Pulper-Gorator unit.

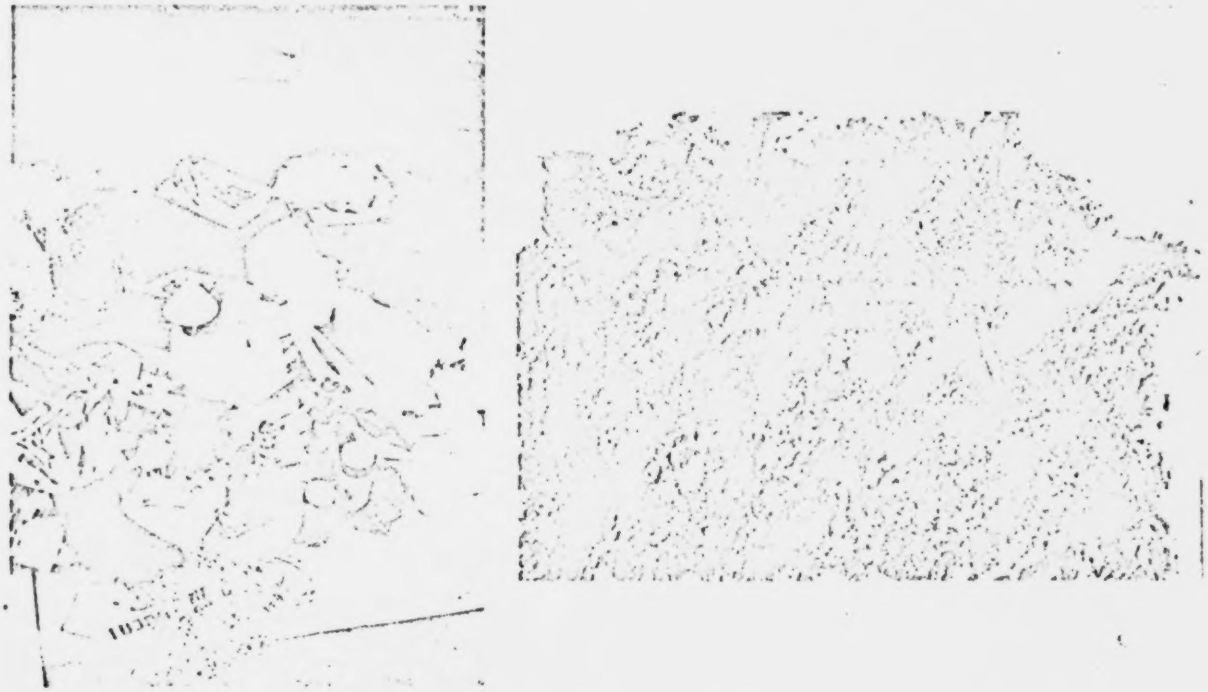


Figure 5 Solid waste before and after passing through Wascon pulper and Gorator

2. pipeline conveyance - Considerable information is available in regard to what is called "solid pipeline". In fact, this mode of transporting

---

* Gorator is marketed by Dorr Oliver Inc. and features a notched, flat-disk impeller mounted at an oblique angle on the end of the shaft. The notches mesh with serrations in the removable liner sections to create a chopping and pumping action.(14)

Pulper was a Weston unit and can admit very large objects and easily shred all components of solid waste except metalic objects which in time will be bent, deformed, disintegrated or rejected.(11)

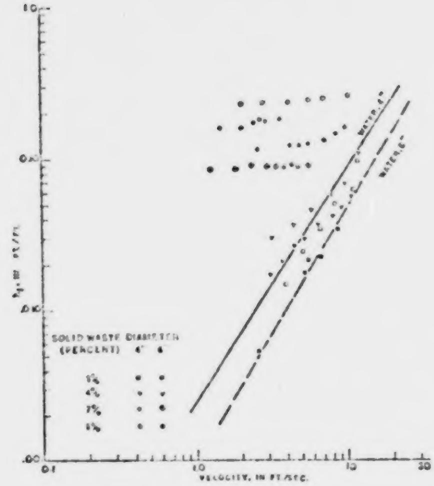


Figure 6a - DIAMETER EFFECT, 8" & 4" PIPE.

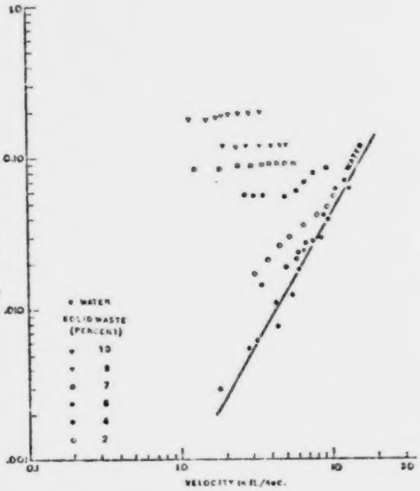


Figure 6b - CONCENTRATION EFFECT, 8" PIPE.

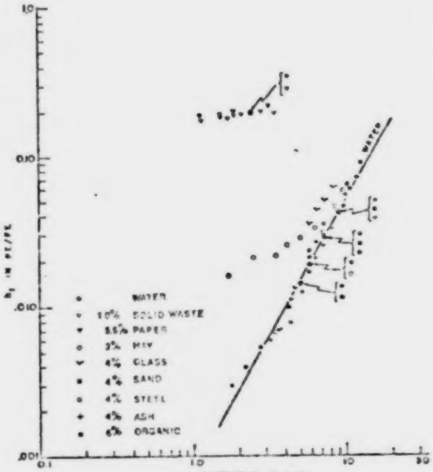


Figure 6c. MAJOR COMPONENTS OF SOLID WASTE & AVERAGE MIX, 8" PIPE.

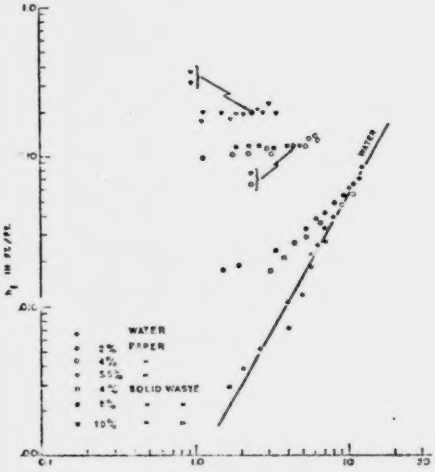


Figure 6d - SOLID WASTE SLURRY (5.5% PAPER) BEHAVES LIKE ITS PAPER COMPONENT, 8" PIPE.

bulk solids is now an industrial reality. However, past experience with solid pipeline has been exclusively with materials which more or less can be characterized as homogeneous. Only recently data regarding solid waste slurry has become available.(12,13)

In these recent publications, head loss data has been presented for slurries created from 1) each major component of solid waste: paper, glass, rags, metals, woods and garbage separately, 2) a synthesized mix with the composition of an average solid waste in the United States, 3) a solid waste mix which was generated in the month of July in the center city of Philadelphia, and finally, 4) ashes produced in the Philadelphia's incinerator.

Figure 6 shows some interesting comparisons. Figure 6a compares the data for the same material but for different pipe diameters. Figure 6b shows concentration effects, and Figure 6c depicts the head loss-velocity relationships for major components of solid waste and the average mix. It is interesting to note that in Figure 6b beyond 7 percent solid waste concentration, the pressure losses are almost independent of average velocity. The explanation may rest on the fact that at high concentration the solid waste slurry forms a stable suspension and moves through the pipe in the form of a plug. This plug flow is observed previously in the slurry of paper stocks. It seems that paper and other fibrous material form a matrix which holds onto the heavy components of solid waste.

Figure 6d shows the pressure losses for different concentrations of solid waste as compared with the pressure losses resulted from slurry flow of paper alone at the equivalent paper concentration. For instance, one may observe that a slurry of 10 percent solid waste which contains 55 percent paper produces pressure losses which are slightly higher than a slurry of 5.5 percent paper alone. This observation forms the basis of a method of prediction of pressure losses of solid waste slurries, a priori, from the knowledge of the pipe diameter, concentration of suspension, mean velocity, and the composition of mix. The pressure loss of a solid waste slurry may be predicted by estimating the pressure loss which may be expected from a paper slurry with concentration equal to the concentration that paper component of the solid waste produces. Therefore, the problem becomes one of the prediction of pressure losses for paper slurries. A number of emperical equations are already available.(15,16,17,18)

For a solid waste slurry of up to 11 percent by weight (weight of municipal solid waste/weight of water)* the pressure loss can be calculated by the following equation:

$$h_f = 9.15 \frac{Q^{0.364} C^{1.89} K}{D^{2.06} (10^2)} \qquad (8)$$

where Q is volumetric suspension flow in gallons per minute, D is inside pipe diameter in inches, and K is the value associated with assorted paper stock which is found in solid waste, and C is the concentration by weight in percentage of the paper component of solid waste in the slurry, and not the concentration of solid waste itself (for instance, the C value for a 10 percent solid waste which contains 55 percent paper is 5.5). For the purpose of the design, equation (8) with $K=0.446$ may be used to predict h_f. To be on the safe side, it is recommended that a safety factor of 1.5 be used until further information becomes available. h_f in equation (8) has a unit of ft.(of water)/ft.(of pipe).

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* Note that because of varied moisture content of solid waste, this is not a precise value. However, at the present state of art, it is sufficiently accurate to be used for the pressure-loss prediction.

Observation, also, reveals another important property of solid waste slurry which relates to the ease of settling of heavier objects. Since the matrix of fibrous material supports heavier objects, the danger of clogging the pipe due to the sedimentation of solids at low velocities is quite small. During the operation of the experimental lines, it was observed that the start of a line after 24 hours shut off can be accomplished without difficulty. This implies that the designer should not be as concerned with critical velocity as he must be for transport of discrete suspensions (such as coal slurry).(9) (See Appendix II.)

IV. How does pneumo-slurry system compare economically with the present truck collection and removal?

An economical comparison of a new technology with an old one is more appropriately accomplished with a number of case studies. The variables are so many that an abstract analysis is rather meaningless. One has to decide for what kind of community and for what level of services the comparison is to be made. It is obvious that a fully automated system of collection and removal of solid waste provides a level of services that is impossible to obtain with the present truck collection system. Also, it is obvious that the economy will be drastically affected with the nature of the community under study. At the present time, economical comparisons for pipeline systems versus truck collection are made for two distinctively different communities: 1) a typical center city of a populated metropolitan area (Center City of Philadelphia, Pennsylvania) and 2) a typical suburb (Radnor, Pennsylvania). The level of service for pipeline transport is taken to be fully automatic while truck collection is obviously semi-manual.

In these studies the cost of truck collection has been compared with the cost of the proposed pipe systems through several steps. First, a compilation was made of the cost of the current collection and removal of waste generated in the study area. Having then looked at the relevant costs of the present system for 1968, a projection of these costs for the future was made. Secondly, a system of pipeline transport for the study area was designed and its cost was estimated. Finally, a benefit-cost analysis was made using the costs of the present system as a measure of the benefits of the proposed pipeline system. An appropriate discount rate (6 percent) was selected to convert all these benefits and costs to a given study date (1968).

a) Center City Philadelphia - The particular study covers 3.2 square miles and about 2.5% of the total city area--and was selected primarily because its boundary closely coincides with census tracts and city solid waste collection routes. This portion of Philadelphia contains the central business district, with much commercial property. There is also a great deal of rental housing, especially in the form of small apartment units. Population of the study area is 48,000, about 2.3% of the city's two million residents.

The collection and removal system in this area includes both city and private operations (large bulky items, especially automoviles, are disposed of by private junk dealers). The city collects all wastes generated by residences (up to a limit) and city institutions with its own truck or through contract with private collectors. Both quantity of waste produced and expenses incurred by the city are well documented.

In the study area, some manufacturing establishments, large wholesalers, commercial companies, and apartment houses utilize private collectors. For central Philadelphia, this part of the collection is considerably larger than city collection. Data regarding the quantity and cost of this portion of collection and removal were lacking, since private collectors do not have to report their activities to the city. This presented a major data problem. To obtain information as to the quantity and cost of private collection, a survey of the area has been made. The survey employed both printed, mailed questionnaires and in-depth telephone interviews, and the results were analyzed statistically. This survey has been described in detail elsewhere;(19) table 1 shows a summary of the information obtained from the survey. (For detail see Appendix III.)

Table 1 - Quantities and costs of truck collection

	Philadelphia			Radnor		
	City Collection	Private Collection	Total	City Collection	Private Collection	Total
Waste quantity in 1968 (thousands of tons)	60.14	193.0	253.0	—	—	30.2
Collection costs in 1968 (millions of dollars)	$ .90	$1.30	$ 2.20	.19	.22	.41
Quantity of waste in 50th year of design period (thousands of tons)	161.9	519.9	681.0	—	—	71.3
Total costs for 50 year design period at 1968 values (millions of dollars)	$27.60	$39.92	$67.50	5.9	6.8	12.7

Note: Data for private collection in the Philadelphia study area were obtained from a mail questionnaire. City data included neither disposal costs, nor the collection and disposal of bulky items, the quantity of which amounted to 4150 tons in 1968, and is estimated to rise to 11,200 tons in the 50th year of the design period. Costs were projected at 4% annual increase basis.

Cost of the present system - Since the aggregate benefits of the new pipeline system represent the sum of the yearly costs of the existing system in the future, a projection of the costs of the existing system over the next 50 years was made. The yearly cost of present system in 1968 was estimated from data supplied by the city and those resulting from the survey. Based on a per capita solid waste increase of no more than 2% per year plus some change in relative labor costs and population level, a yearly cost increase of 4.0% was assumed (According to city estimates, the volume of city collections has been increasing at the rate of 2-3% per year in recent years) and yearly cost for each year of the next 51 years were estimated. These yearly values then were discounted at a rate of 6% to the 1968 base and summed up to estimate the direct benefit of the new system.

The private yearly collection costs were obtained from the previously mentioned survey.* This yearly expenditure was also assumed to increase annually at a rate of 4%, and was again discounted at the rate of 6% per year to convert it to the present day value for the next 50 years. The two when added yields the total collection and removal costs over the next 50 years in the study area, adjusted to 1968 cost. Three alternate points of disposal have been selected: zero, 20 and 50 miles from the boundary of the study area (See table 1).

Pipeline system costs - In order to estimate the cost of the pipeline system, a number of alternative networks has been examined. The main criterion for the selection of any design has been that it should accomplish the task with the present technology. In other words, the designs that has been examined could be built today. They would be inefficient as compared with a refined system, and certainly would have problems, but they would be operative.

The final scheme adopted for comparison has been a combination of pneumatic and slurry pipelines. The pneumatic system would collect at four points all solid waste generated from individual buildings in the study area. Then, at each point, waste water from the sewerage system (only a few percent of the total produced) is mixed with the solid waste to produce a 6% slurry. The mixture then is fed into, respectively, a Wascon pulper and a Gorator. The Gorator produces enough head to convey the slurry to the boundary of the system, from whence the slurry can be pumped as far as desired for disposal. The pneumatic part of the system basically is the same as the unit already in operation in Sundeberg, Sweden. The slurry pipeline has been designed from information outlined in previous sections.

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* It should be noted that the survey predicted the amount of solid waste collected by the city of Philadelphia within 9% of the actual value based on Sanitation Department figures. This result has been interpreted as an independent check on the accuracy of the survey.

The cost of pipeline systems has been estimated with care and rather in the high side. They were checked with a number of consulting firms and are about the same as those used by Philadelphia's Water Department. All costs, including installations, operation, and maintenance, were considered. Three alternate points of disposal have been selected: zero, 20, and 50 miles from the boundary of the study area (see table 2). Comparison was made for the design period of 50 years (see table 3).

Table 2 - Projected costs for pipeline network

	Philadelphia			Radnor					
				Plan 1			Plan 2		
	Distance from study area to disposal point			Distance from study area			Distance from study area		
	0	20 miles	50 miles	0	20 miles	50 miles	0	20 miles	50 miles
	(millions of dollars)			(millions of dollars)			(millions of dollars)		
Pipe costs	$25.20	$30.00	$37.10	$20.60	23.00	26.60	20.60	23.00	26.60
Air seals and house fittings	68.02	68.02	68.02	20.16	20.16	20.16	9.24	9.24	9.24
Crusher and pump	2.08	2.08	2.08	1.00	1.00	1.00	0.90	0.90	0.90
Vacuum blowers and filters	0.97	0.97	0.97	0.55	0.55	0.55	0.55	0.55	0.55
Slurry pumps and pump or blower houses	1.00	1.39	2.03	1.00	1.31	1.84	1.00	1.31	1.84
Operation	10.17	12.10	14.20	2.38	2.48	2.56	2.38	2.48	2.56
Maintenance	18.48	18.84	19.41	7.62	7.78	8.10	4.90	5.08	5.37
Supplementary collection of bulky materials ($20/ton)	3.0	3.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0
Total cost	$128.9	$136.4	$146.8	54.31	57.30	61.81	41.67	44.66	49.16

Costs and benefits comparison (pipeline system vs. truck collection)[a] - Table 3

Study Area	—		With present technological capabilities (millions of dollars) (These systems can be constructed today)						With moderate advances[b] in crushing and pumping techniques and cost reduction of discharge valves due to mass production					
Philadelphia	Distance to disposal site		0 miles		20 miles[c,d]		50 miles[c,d]		0 miles		20 miles[c,d]		50 miles[c,d]	
	Mode of collection		Truck Collection	Pipeline[e] Collection	Truck Collection	Pipeline[e] Collection	Truck Collection	Pipeline[e] Collection	Truck Collection	Pipeline[e] Collection	Truck Collection	Pipeline[e] Collection	Truck Collection	Pipeline[e] Collection
	50 Year study period		57.5	128.9	100.6	136.4	153.2	145.8	57.50	105.5	100.5	112.7	153.2	122.6
Radnor	Plan 1	50 Year study period	12.70	54.31	15.30	57.30	19.30	61.81	12.70	47.60	15.30	50.60	19.30	54.10
	Plan 2		11.70	41.70	15.30	44.70	19.30	49.16	12.70	38.40	15.30	41.40	19.30	45.90

(a) The indirect benefits of pipeline systems are not included in this comparison.

(b) A 25% decrease in the costs of blowers, crusher-pumps and discharge valves (vacuum seals) is assumed.

(c) Cost of truck transport assumed to be 5¢/ton/mile.

(d) An annual increase of 2.0% in quantity of solid waste is assumed

(e) These figures include the collection of bulky material which is $3,000,000 over the next 50 years at the 1968 cost (estimated that it will cost $20/ton to remove the bulky materials).

According to these estimates, the city of Philadelphia will have to spend, in direct costs, some $153.2 million to collect and remove to a distance of 50 miles the solid waste which will be generated in the study area for the next 50 years. For this same period, the cost of a 50 mile solid waste pipeline is estimated to be $146.8 million. These figures show that pipeline transport of solid waste, economically speaking, would be competitive with the present truck collection, even disregarding the secondary benefits of the pipeline system. Details of the above analysis are reported elsewhere.(4) (For detail see Appendix IV.)

(b) Radnor - The study area covers 14.0 square miles of mostly residential suburb containing approximately 7100 property units. Population of township is 30,000. The total length of streets in the study area is 115 miles. The total quantity of solid waste generated in 1968 and the cost of truck collection is shown in table 1.

The economy of truck collection was compared versus pneumo-slurry pipeline by employing the same technique which was outlined for Center City of Philadelphia. Two pneumo-slurry systems were studied: "plan 1" and "plan 2". These two plans refer to alternative arrangements of the installation of pneumatic systems. Under plan 1, all single dwellings would have a collection port, a collection port would be provided for every five apartments, and a collection port would be located in each business establishment. Under plan 2, every four single dwellings, every 15 apartment units, and each business would have a collection port. Table 2, shows the projected cost of pipeline network. Table 3, shows the comparisons. From the table it appears that pneumo-slurry transport of solid waste would be at best about twice as costly as truck collection for a residential suburb similar to Radnor, Pennsylvania

The results of these economical studies are to be expected because of the nature of two communities investigated and the characteristic of pneumo-slurry systems. Pipeline transport becomes economical when the quantity of transported materials is high. Center City Philadelphia generates solid waste almost 40 times as much as Radnor. There are 115 miles of roads in Radnor as compared with the 72 miles in Philadelphia. It becomes apparent that there is less use of the pipeline system in Radnor. Hayden(20) suggests a usage factor (defined as tons of solid waste per year generated, divided by miles of pipe to be installed) as a criterion for rough estimate of the economy of the pneumo-slurry pipeline. For Center City Philadelphia, this usage factor is 2400, while for Radnor it is 315. Based on intuitive reasoning one may speculate that perhaps for usage factor of 1000 or above, the pneumo-slurry system may become economically attractive.

V - Additional Factors - There are several other points which we must discuss. The basic premise of the economic comparison has been that no new devices will be available. However, it seems only natural to look into the future with some expectation and hope. First, it is clearly reasonable to assume that a more efficient crusher-pump unit will be developed. In the study reported, for instance, it was assumed that 15 Wascon pulpers were needed at each collection point. It is obvious that without much effort the capacity of these pulpers can be increased. In addition, the cost estimates for different units are based on present prices, and these units are now manufactured separately because of a limited market. Once a demand is developed, a considerable reduction in price can be expected. Wascon's engineers predict a 30-40% reduction in the cost of their unit. Second, it is clear that the major portion of the cost of the pneumo-slurry system is the installation of the collection port assembly at each building. The cost of this item has been reduced by 40% in one year (1968) --- even without the cost-reducing incentive of mass production.

Table 3 also indicates a cost for the pipeline system that assumes some reasonable future development. The economy of the proposed system is obvious.

- The pneumo-slurry system can not handle bulky materials. A small inexpensive supplementary truck collection by the city is required. This supplementary cost is included in the economic analysis.

- There are large shredding units available on the market which may be used in a slurry pipeline scheme. These large shredding units would reduce the size of the material collected in the pneumatic pipeline and also crush and shred the large, bulky items not transportable in the pipeline. Thus, large items would only have to be taken short distances to the local crushing station.

- The indirect benefits of the pipeline system (such as elimination of the disadvantages of the present system), which make it even more attractive, are not included in the comparison. In addition, no mention is made of the mode of disposal. Obviously, the interrelationship between the collection system and the method of disposal is significant. There can be no doubt that, if the pipeline collection and removal of solid waste wins acceptance, changes in methods of disposal will be forthcoming.

The trend in solid waste disposal is toward conservation and reuse, and, since all reuse systems utilize crushers, it is altogether possible that crushing of solid waste for pipe transport could be the first step of a disposal process. The effect that slurry disposal may have on the management of air and water needs to be examined carefully.

- One major indirect advantage of pipeline transport of solid waste is the flexibility in the selection of disposal site. The previously mentioned study clearly indicates that the longer the distance to a disposal site, the more economical the pipeline transport will be. In view of diminishing available lands close to the centers of population, this is quite significant.

ⓑ The estimated rate of increase (2%) of solid waste generation in the study area is much less than that predicted by others. From the standpoint of economical comparison, the lower rate is a conservative assumption. The more waste to be handled, the less expensive the pipeline will be for a ton of waste; costs of truck collection will increase proportionately.

ⓒ A potentially significant advantage of the solid waste pipeline is the possibility of attaining high efficiency due to economies of scale. Vast areas with a large population could be connected and operated as a part of one system. The scale of operation will justify the maintenance of high caliber operating personnel and application of the most advanced technology. Small towns, which, at the present time, cannot afford trained manpower and suffer from lack of know-how, can easily take advantage of joining a much larger collection group.

ⓓ Finally, it should be abundantly clear that while this report is optimistic, it does not minimize the problems involved in actual installation of a pipeline system. We do not imply that all technological problems are solved, that all economical considerations were reckoned with, or that any of the social implications of such a system were investigated. All we intend is to establish a dialogue to encourage further thought and interest in this area. To be sure, there are many knotty problems which should be surmounted before pipeline transport of solid waste becomes a reality. Such a pipe system, while eliminating or reducing many current problems, would bring forth other problems. Although these problems may be overwhelming and the initial capital required is huge, the gains are attractive.

VI - Acknowledgement. - This paper is the final report of research project 2RO1 UI 00541-01204 U.S. Office of Solid Waste. It is in fact a summary of a series of papers previously published in various journals, with a number of co-authors of whom Dr. John A. Hayden was the major contributor. Much more information can be obtained by referring to those previous publications which are sited in the bibliography.

Nomenclature

C - concentration by weight of paper component of solid waste, per cent; 0.446;

D - inside pipe diameter, inches.

F - tangent of the angle of slide

g - acceleration of gravity, ft/sec^2;

q - volumetric suspension flow, gpm;

H - elevation, ft;

h - total vacuum in inches of water

h_f - pressure loss due to the slurry flow,

K -

l - distance traveled in the elbow, ft;

L - horizontal distance, ft;

M - quantity of solids to be transported in pneumatic system, lbs/min;

P - total power requirement for pneumatic system, ft.lbs/min;

P_a - power loss due to the air flow, ft.lbs/min;

P_{ac} - collection losses, ft.lbs/min;

P_{af} - filter losses, ft.lbs/min;

P_{ap} - pipe losses, ft.lbs/min;

P_{as} - separation losses, ft.lbs/min;

P_m - power loss due to material flow, ft.lbs/min;

P_{m1} - acceleration power, ft.lbs/min;

P_{m2} - elevation power, ft.lbs/min;

P_{m3} - power to sustain horizontal motion, ft.lbs/min;

P_{m4} - minor power losses for materials, ft.lbs/min;

Q - air flow, ft^3/min;

R - radius of elbows, ft;

V - mean air velocity, ft/sec;

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Appendix I

Size Reduction of Municipal Solid Waste

This material was prepared by Mr. D. E. Keyt for the project.

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Summary

It is the policy of most manufacturers of crushing equipment to carefully match the machine used to crush a particular material to the material being crushed, so that efficient crushing will result. Since refuse contains samples of all kinds of materials, few, if any, machines are available which will completely break up unsorted trash. The hammermill seems to be the crusher best adapted to the crushing of refuse. Because it combines shear, tension and compression in the fracturing process, it can break up a wide range of materials. It can also be designed to expel large dense ductile objects such as bolts and pipe fittings, thereby preventing destruction or jamming of the machine. It may be necessary to employ a two stage crushing process or to use a closed loop system in order to end up with a particle size which is small enough to be carried in a water slurry.

Introduction

Since ancient times, man has used tools to reduce the size of raw materials with which he is working. Perhaps the morter and pestle was the first such tool. Much later after the invention of the waterwheel and steam engine he mechanized the milling operation. Today there are a vast number of a wide variety of mills and grinders in use. They range in size from pepper grinders found on the family table to huge machines which grind up boulders into powder or reduce automobile bodies to a pile of chips. One characteristic that nearly all of the grinders have in common is that they are designed, built, and used to reduce in size one particular substance.

Depending on the characteristics of the material to be reduced, the three common methods of stressing a material are used either singly or in combination. Brittle abrasive materials are loaded in compression until they crumble. Fibrous and plastic materials are decreased in size by a shearing or cutting action. Some machines use tensile loading to cause the break-up of the materials being disintegrated, but this method is used by very few types of machines except as combined with shearing. All three fracture methods are used in some machines, notably the hammermill, to obtain the desired end.

The reducing in size of domestic waste puts requirements on the grinding machines beyond those of any single material heretofore processed, since such waste is composed of all kinds and sizes of materials. It is safe to say that no grinding or milling machine has ever been built that can will disintegrate any material that might be dropped into it. Some machines will crush boulders to powder but jam to a stop when newspaper is introduced into the machine hopper. Other machines chop merrily away on paper or plastic, but jerk to a halt when a small screw drops into its teeth.

Requirements of Waste Grinding System

Picture a room located deep in a building which contains a large grinding machine, a pump, and some large pipes. Over the machine is a walkway along which any person can drop a can of trash and from which he can dump the trash onto a conveyor belt leading to the crusher or perhaps dump it directly into the machine. Some persons get rid of their refuse at 8:00 A.M. others at 11:00 P.M. It is desirable, therefore, that the room be open at all hours of the day. Such availability has the added advantage that the system can be smaller since the load is distributed over a greater period of time. Now imagine trying to find and keep persons available at all hours who can and will sort through the incoming trash to remove objects that the crushing machine will not accept or which could even destroy the machine. With these thoughts in mind, it will be realized that one of the basic requirements of crushing machines for the reduction of municipal wastes is that it must operate unattended and accept unsorted refuse. The health problem alone would be a sufficient reason for removing from consideration the sorting of the incoming trash. This means that the machine must accept any conceivable material object without jamming or breaking. It does not necessarily mean that all objects must be ground up.

Inasmuch as the grinding machine is to prepare the trash in a form which can be carried in a water slurry, the second basic requirement is that the machine grind all materials received, except some which may be disgorged, into fine enough particles that they may be carried by water, regardless of their density.

A third requirement is that the machine's first cost be as low as possible, and a fourth requirement is that the operating cost (power and maintenance) be minimal. While these last two requirements are extremely important for the overall system to be economically feasible, at the present time they are academic, because a low cost efficient machine which will not grind refuse is useless. At the present time, the object should be to develop a system which will work. If this can be done, then steps should be taken to reduce its cost and to improve its efficiency. This study has been concerned primarily with the first and most important of the four basic requirements included here, the finding of a suitable reduction method.

Investigation

In order to tap the wealth of experience of the many crusher manufacturers, a questionnaire was prepared (see appendix 1) which listed items which are typical of those found in solid residential and commercial waste. The questionnaire inquired as to what existing machines, available from the manufactures questioned, would do to these items, if such items were dropped into the crushing machines. Approximately twenty-five companies were contacted and ten sent back the filled-in questionnaires. Most filled in questionnaires for several types of crushers, so a very broad coverage was obtained in spite of the moderate number of replies. A fair number of manufacturers sent illustrative brochures only or simply stated that their crusher was not applicable. Actually, since the purpose of this portion of the investigation was to determine the strengths and weaknesses of different types of crushers, a filled-in questionnaire was useful, even if the particular crusher was considered not applicable for the purpose of crushing trash.

Results of Investigation

Of the items listed on the questionnaire, most could be pulverized by nearly all of the crushers. Glass appears to be one of the easiest materials to handle while paper, books, plastic bottles, aluminum foil, bricks, foam rubber, tin cans and similar articles cause no problems. Many machines will reduce refuse the size of these items to only about one inch with a lower limit of about 1/4 inch.

At the other extreme, large bolts must be rejected or else they will jam essentially all of the machine. Other similar items such as hand tools cause similar problems. Coils of wire jam up many machines but can be handled by some hammermills. Small appliances behave in the same manner. One special problem is the automobile tire. While tires can be cut up with a cutter and even with hammermills, it should be possible to exclude them from the pulverizer by limiting the opening through which the trash is dumped, if they present too much of a problem.

Wooden boards are another difficult to handle item if they are too large. Here, a size limitation based on the inlet opening would be useless because even 2" x 4" sized pieces can cause trouble in the crusher.

A number of companies have used pulverizers to break up solid refuse. Those who appear to have been most successful in this area are:

General Products of Ohio
Crestline, Ohio 44827

The Black Clawson Company
Middleton, Ohio 45042

Williams Patent Crusher and Pulverizer Co., Inc.
2701 North Broadway
St. Louis, Missouri 63102

Stedman Foundry and Machine Co.
Aurora, Indiana

The Heil Co.
3000 W. Montana Street
Milwaukee, Wisconsin 53201

The above companies have built machines which will handle unpicked rubbish. Items which cannot be pulverized are thrown out of the machine by various means. While most machines appear to operate dry as the usual mode, the questionnaire indicated that a number could be run either wet or dry.

Conclusions

It would appear that some kind of a hammermill would provide the best solution to the waste crushing problem. All of the machines which have been successfully used for this purpose resemble hammermills, whether they are actually given the name or not. The reason that the hammermill is such a good choice is because it can be built to provide both shear and compressive stresses for the purpose of fracturing the material fed into it. A single pass through a hammermill may not result in an effluent which is small enough to be carried by water in a slurry. It may be necessary to use at least two or more such mills in series so that the end product will be fine enough. Alternatively, a feedback system may be used where pieces too large to drop through a screen are sent back by conveyor for further processing in the crusher. Large dense uncrushable items must be allowed to accumulate and be transported by truck to a disposal location or perhaps be sold for reclamation purposes.

Appendices

1. Sample questionnaire

2. Description of crushers

    a. Hammermill
        (1) Swing hammer with cage
        (2) Rolling ring hammermill with cage
        (3) Impactor, swing hammer
        (4) Fixed hammer

    b. Impellor type pulverizer

    c. Cutter

    d. Jaw Crusher

    e. Gyratory crushers

    f. Roll crushers
        (1) Single roll
        (2) Double roll

    g. Cage mills

    h. Ball mills

    i. Attrition mills

    j. Mullers

SOLID REFUSE DISINTEGRATION STUDY QUESTIONNAIRE

Name of Company STEDMAN Fdy. + Mach. Co

Type of Machine (e.g. ball crusher) Swing Hammer + Rolling Ring

Operation is Wet Only _____ Dry Only _____ Wet or Dry ✓

Based on past experience, describe the effluent (or effect on machine) if the items listed in the left column are fed into this type of machine. Place a letter in the column whose heading most nearly represents the effluent. Use "F"=known fact, "O"= opinion.

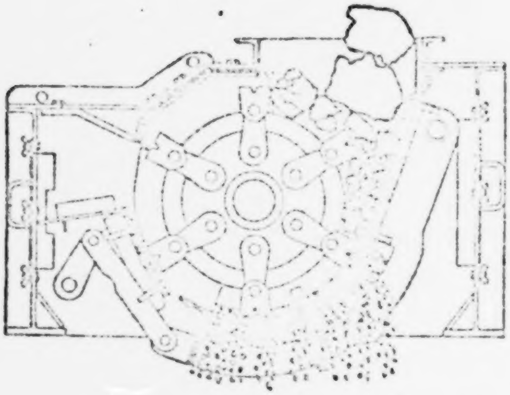
INPUT \ OUTPUT	Tiny particles (1/100 inch)	Small particles (1/16 inch)	Medium particles (1/4 inch)	Large pieces (1 inch)	Compressed Chunks	Flattened Chunks	Long Fibers	Will cause machine to fail.
Newspapers			F					
Books				F				
Rags				F				
Cotton				F				
Foam rubber				F				
Auto tire								O
Shoes				F				
Plastic bottles			F					
Bones			F					
Garbage			F					
Glass bottles		F						
Bricks		F						
Wood				F				
Small appliances				F				
Tin cans				F				
Clothes hangers						F		
Aluminum foil				F				
Hand tools				F				
Metal chips				F				
Razor blades				O				
Large bolts								O
Pipe fittings				F				
Coils of wire				F				
Plastic bags				O				

Please return this questionnaire to D.E. Keyt, 113 Towne Bldg., University of Pennsylvan
Philadelphia, Penna. 19104

Hammermills

(1) Swing hammer with cage

Large heavy swinging hammers strike incoming material and break it up. As material is reduced in size, it falls through openings in the cage or grate. The rubbing of the material over the grate causes rapid wear. Figure 1 shows such a crusher. Figure 2 shows a modification which allows for the dropping out of items which cannot be crushed. Longer life is obtained, also, because the hammers can be reversed. Note that objects which cannot be handled will not damage the machine since the hammers can swing out of the ~~cage~~ WAY.



This illustration shows how material must remain in hammermill grate bar chamber until crushed small enough to pass bar openings. The reduction in this mill is mostly by attrition.

Figure 1
Hammermill
Pennsylvania
Crusher Division
West Chester, Penna.

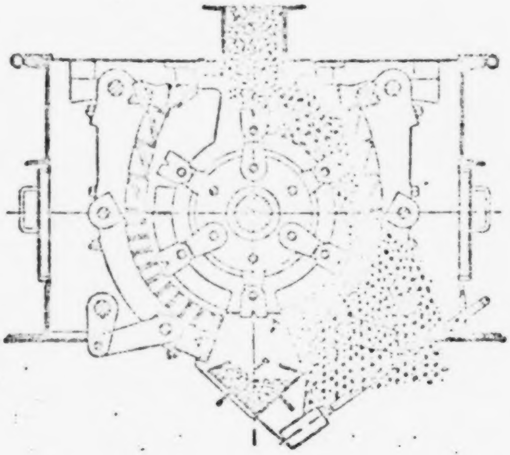


Figure 2
Reversible Hammermill
Pennsylvania Crusher
Division, West Chester
Penna.

Hammermills

(2) Rolling ring hammermill with cage

In order to reduce wear in a hammermille, the hammers can be replaced by rings which are free to roll as the rotor turns. Instead of a rubbing action, there is rolling with nearly pure compression loading on the material in the crusher. Figure 3 shows an example of such a crusher.

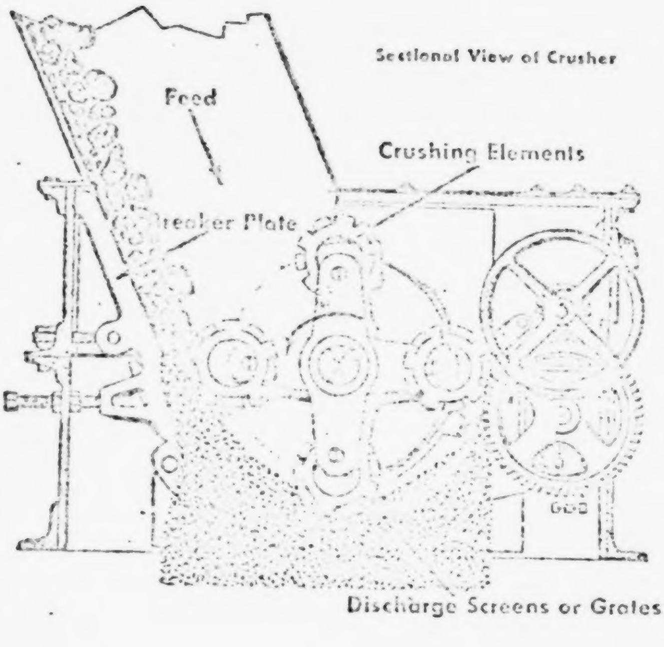

Sectional View of Crusher
Feed
Crushing Elements
Breaker Plate
Discharge Screens or Grates

Figure 3. Rolling Ring Hammer Mill
American Pulverizer Company
St. Louis, Missouri

Hammermills

Impactor, Swing Hammer Type

Instead of using a grate over which the hammers swing, the impactor contains a number of deflector plates against material which is being broken is caused to strike. The material thus strikes the hammer, the deflectors, and other pieces of the substance being broken up. Both large and small objects can fall from the machine, so it is necessary to recycle the large pieces.

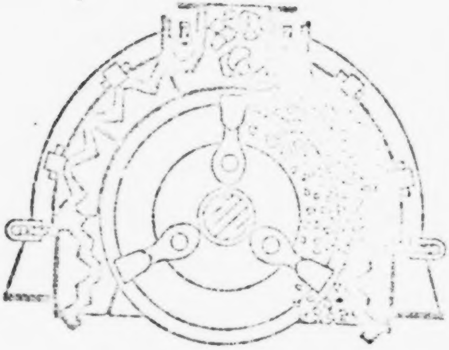


Figure 4a. Impactor
Penna. Crusher Div.
West Chester, Pa.

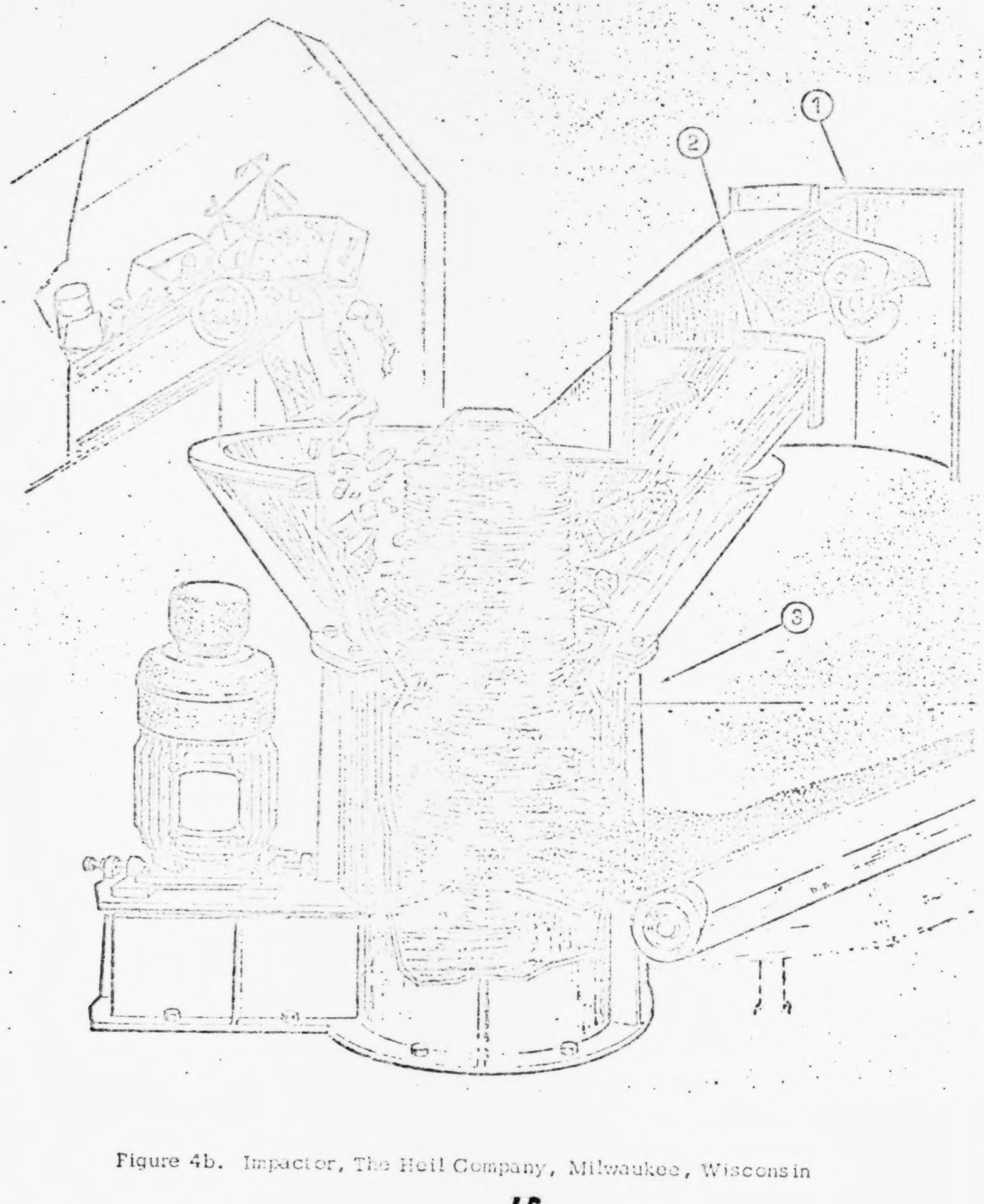


Figure 4b. Impactor, The Heil Company, Milwaukee, Wisconsin

Hammermills

Fixed Hammer

Some hammermills use hammers which do not swing. Unless the machine is extremely rugged, such a design is not applicable to rubbish because the hammers cannot swing out of the way to allow the uncrushable object to pass. Such a design is particularly adaptable to the reducing in size of a single uniform substance.

Impellor type Pulverizer

This type of pulverizer reduces the size of the infeed by impact, shear and attrition. Large, uncrushable items can be thrown out or continually impacted until either the object or the machine breaks.

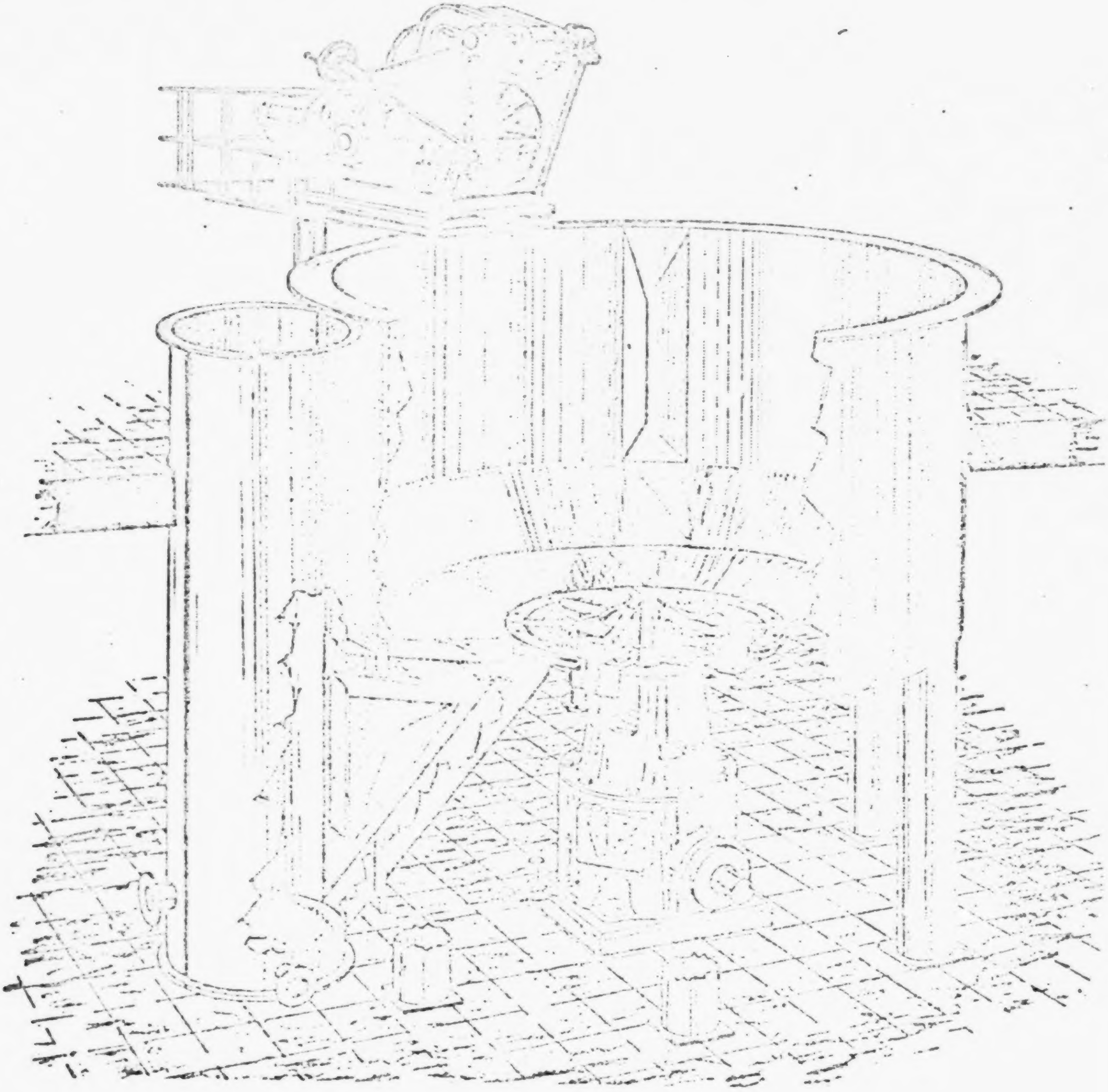


Figure 6a. Jones Sark Continuous Waste Pulper
Pittsfield, Mass.

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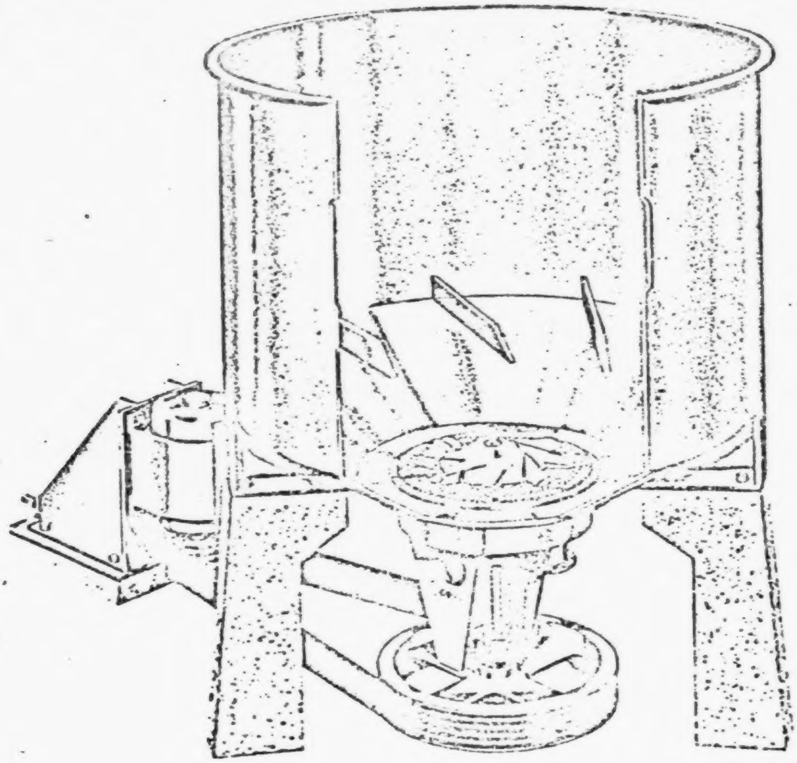


Figure 6b. Hydropulper
Black Clawson
Middletown, Ohio

Cutter

Especially useful for the purpose of shredding plastic, paper, bones, cloth, tires and even glass is the cutter type pulverizer. Such a machine is generally not applicable for the reducing in size of solid metal parts. Some are shaped like wood planers, others like a series of circular saw blades stacked side by side.

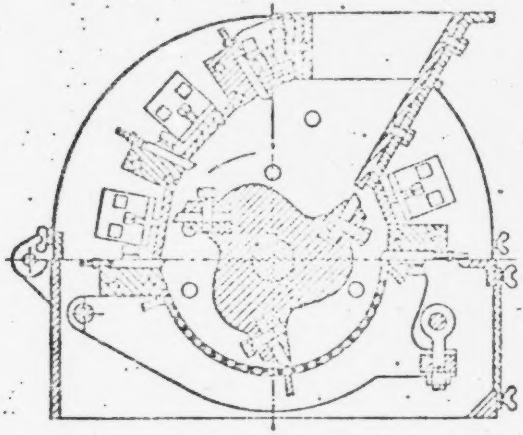


Figure 7. Cutter, wood pulverizer type
American Pulverizer Company, St. Louis, Missouri

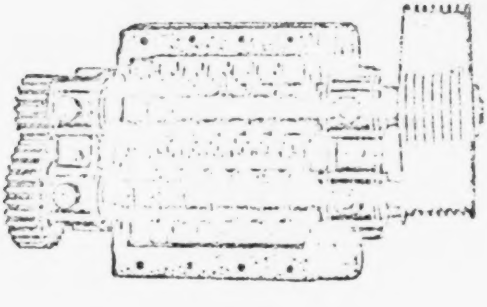
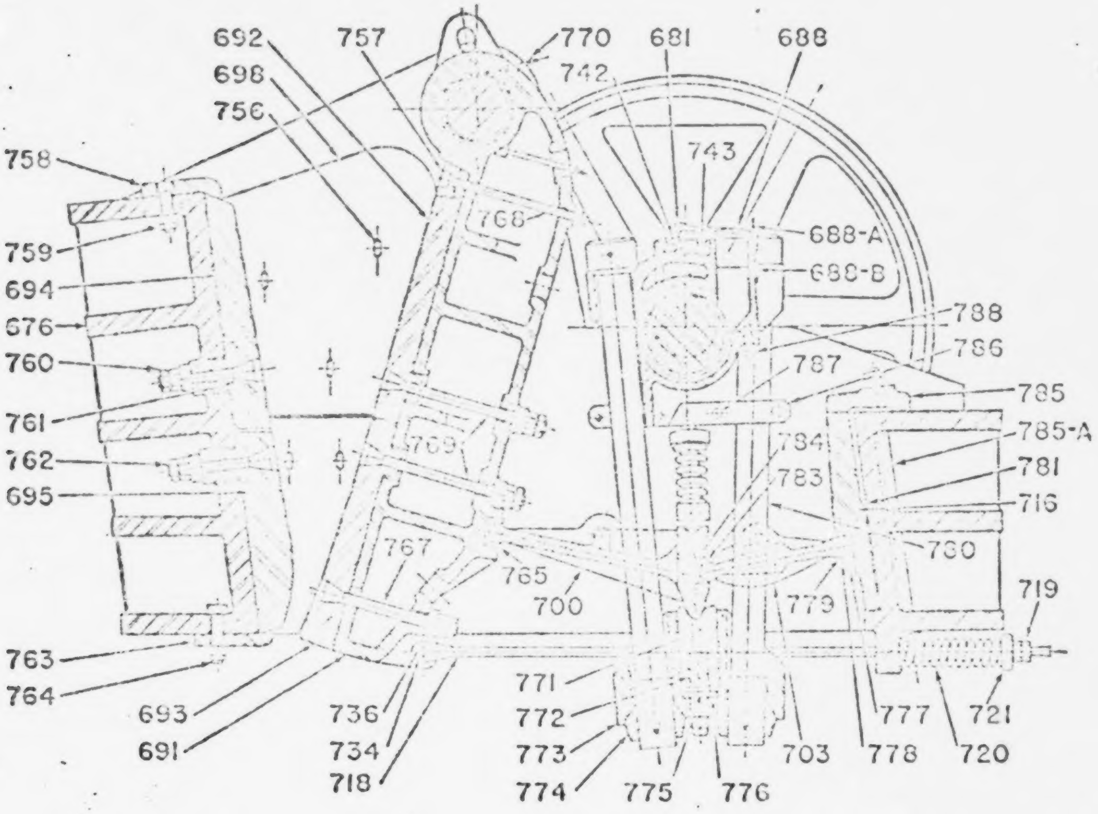


Figure 8. Saw tooth cutter, Young Machinery Co.
Muncy, Pa.

Jaw Crusher

The jaw crusher is primarily useful for the purpose of reducing in size friable materials. The machine contains a fixed and a movable jaw. As the movable jaw moves away from the fixed jaw, the material contained in the crusher drops to a lower level. Then as the movable jaw returns, the particles are squeezed and caused to break up into even smaller particles. By the time that the substance drops through the bottom, it has been reduced in size an amount depending on the opening at the bottom of the crusher.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775
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Figure 9. Jaw Crusher, Taylor Engineering & Manuf. Co.
Allentown, Pa.

Gyratory Crusher

The gyratory crusher is essentially a rotary version of the jaw crusher. An eccentric rotor causes the squeezing in this case. ~~In~~ See Figure 10 below.

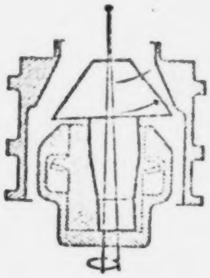

Figure 10. Gyratory Crusher
Pennsylvania Crusher Division
West Chester, Pennsylvania

Roll Crusher

(1) Single Roll

While the roll crusher has primarily been used for breaking friable materials as shown in Figure 11, by placing large massive projections on the roll, a machine has been developed which can act as a first stage crusher or prebreaker. Figure 12 shows such a machine.

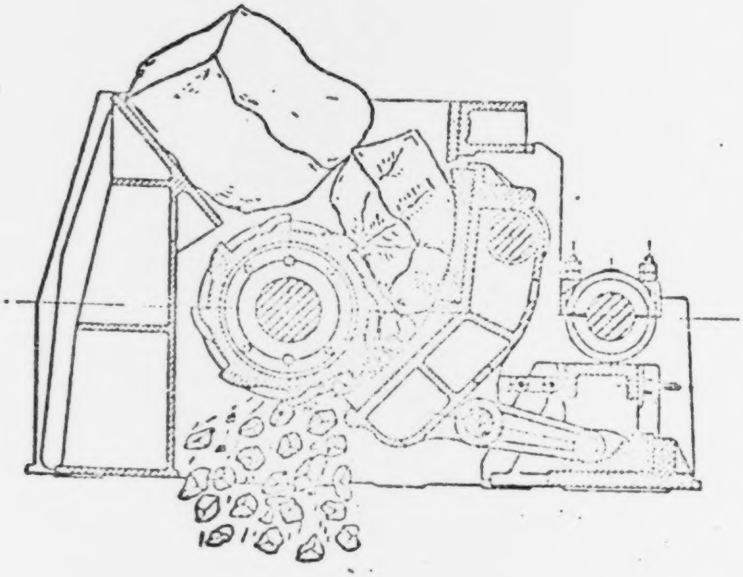

Figure 11. Single Roll Crusher
Pennsylvania Crusher Division
West Chester, Pa.

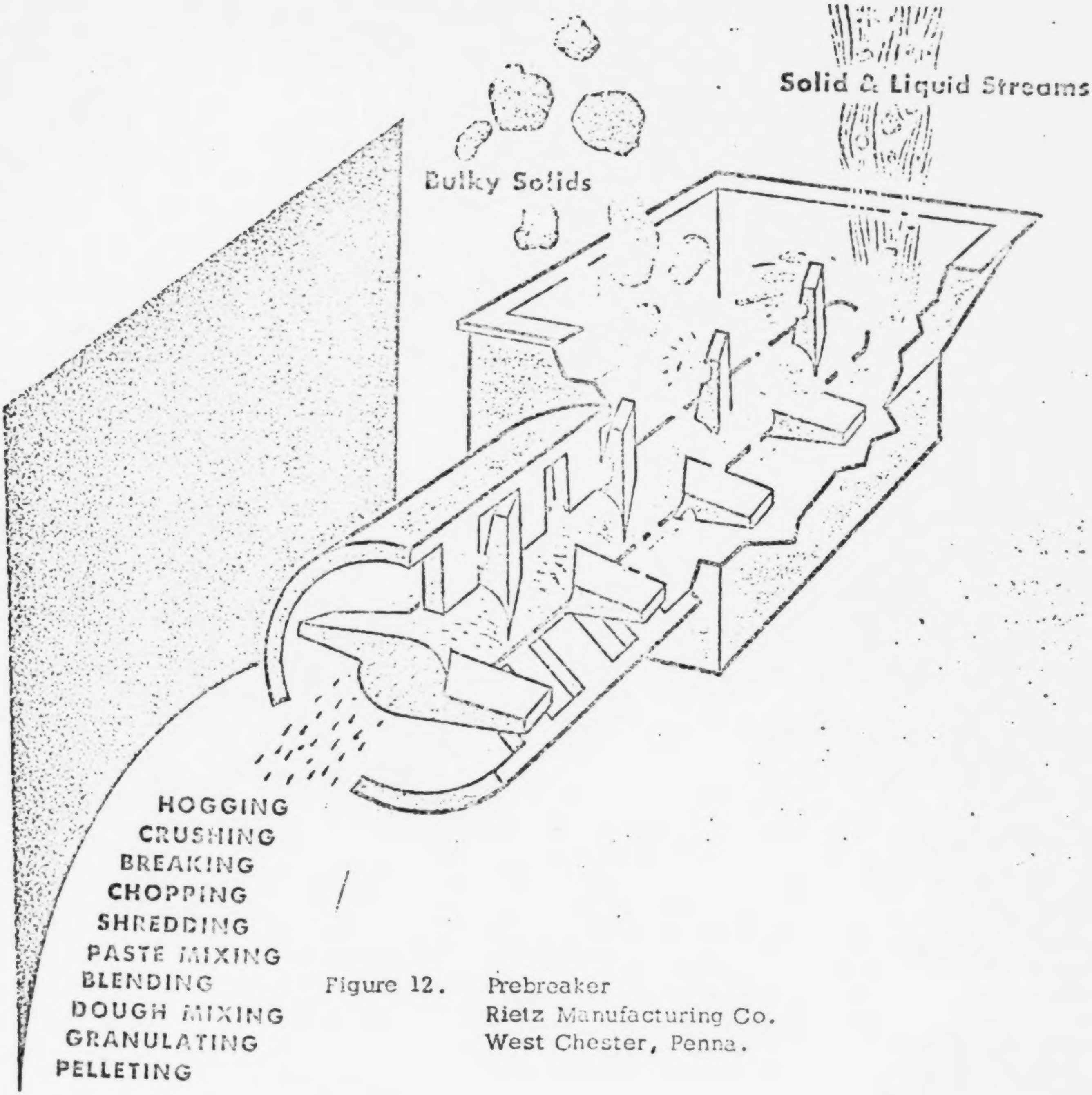
Solid & Liquid Streams
Bulky Solids
HOGGING
CRUSHING
BREAKING
CHOPPING
SHREDDING
PASTE MIXING
BLENDING
DOUGH MIXING
GRANULATING
PELLETING

Figure 12. Prebreaker
Rietz Manufacturing Co.
West Chester, Penna.

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Roll Crusher

Double Roll

The double roll crusher is used primarily to reduce materials to fine powders. It is not applicable for the purpose of reducing rubbish.

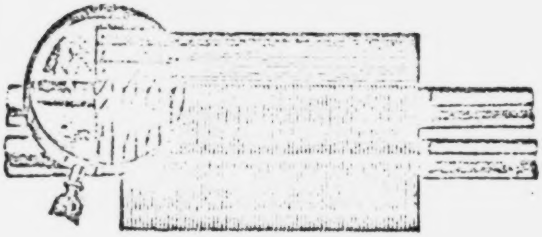

Figure 13 Double Roll Crusher
Sprout-Waldron
Muncy, Pennsylvania

Cage Mills

The material to be pulverized is dropped into a rotating cage. The crushing action occurs as a result of falling impacting particles, impaction between particles and the cage, and in some designs with impingent of the material on deflection plates surrounding the cage. Such a design would fill up fairly rapidly if trash was the material being reduced.

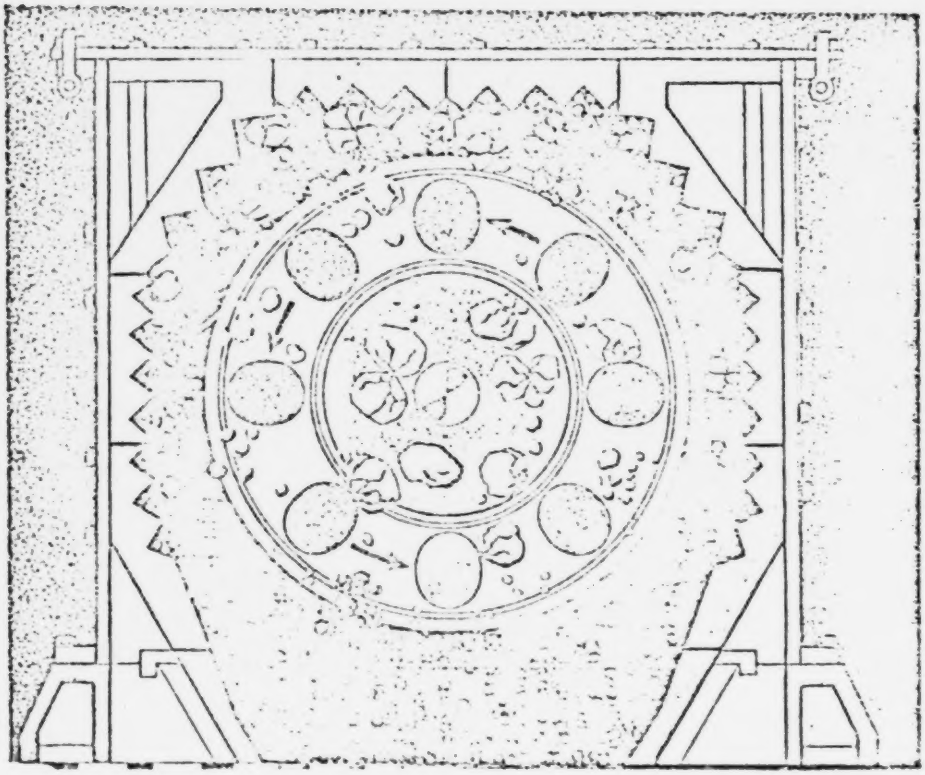

Figure 14. Cage Mill
Stedman Foundry & Machine Co., Inc.
Aurora, Indiana

Ball Mills

Some crushers of the cage type employ a heavy cage which contains a large number of steel balls. As the cage rotates, the steel balls strike material fed into the cage and cause metal parts to work harden. As the action continues, ductile materials become brittle and brittle materials gradually crumble. Unfortunately, the same action which causes the material being pulverized to break up also has the same effect on the balls and the cage. Hence maintenance is a problem with this type of crusher. Substances such as paper and plastic are not readily disintegrated in this type of machine.

Attrition Mills

If two surfaces having rough surfaces are moved relative to each other, material which is dropped between the two surfaces as this action occurs will be reduced in size if the material is softer than the surfaces of the machines. This type of machine is used primarily to defiberize, grind, granulate fabrics, plastics, rubber, etc. They are not applicable to pulverization of metals

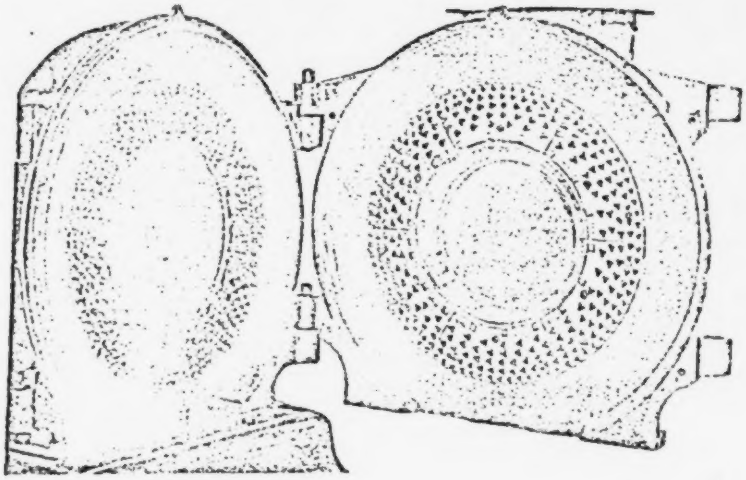

Figure 15. Disk type attrition mill
Sprout-Waldron
Muncy, Pennsylvania

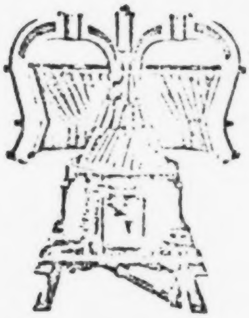

Figure 16. Conical type attrition mill
Sturtevant Mill Co.
Boston, Mass.

Mullers

Mullers are used to reduce materials to fine powders much as in a m$\overset{o}{a}$rter and p$\overset{e}{i}$stle. Such a machine has no application for trash size reduction.

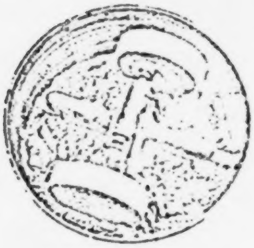

Figure 17. Muller
National Engineering Co.
Chicago, Illinois

Appendix II

The Flow Properties of Solid Waste Slurries

Note: This paper reports data on the flow of municipal solid waste slurries in pipelines. In addition, it presents a prediction equation which permits the calculation of the pressure losses from the knowledge of pipe diameter, mean velocity, and concentration of the solid waste slurry. A significant finding of this work is that a municipal solid waste slurry behaves, from the standpoint of pressure losses, identically with a paper (of the type and composition which is found in solid waste) slurry having a concentration equal to the fraction of paper in the solid waste times the concentration of the solid waste. Additional information is provided in regard to shredding of solid waste.

This material was published by Iraj Zandi and John A. Hayden in the Journal of Compost Science, April 1971.

1. INTRODUCTION

The Economics of collection and removal of solid wastes from the center city of a typical metropolitan area via pipeline has been reported and discussed elsewhere (Ref. 1,2,3). In brief, they indicate that a fully automated system of solid waste collection and removal will be less expensive than the present truck collection over a period of fifty years, when the character of the community is similar to the center city of Philadelphia, U.S.A. A similar study (Ref. 4) for a residential community (Radnor, Pennsylvania, U.S.A., 3,000 population) shows that the proposed system would cost somewhat more than twice the present truck collection. However, should one access to the system be provided for every three or four houses (instead of for each house) the solid waste pipeline again becomes economically attractive. Figure 1 shows the artist's view of the proposed pneumo-slurry system. It is called pneumo-slurry system because it utilizes both pneumatic and slurry pipelines. Fig. 2 indicates a schematic diagram of a possible collection-disposal combination which is not only fully automatic but utilizes the pipeline as a biological reactor to treat the organic portion of solid waste.

While information on the technological feasibility of vacuum collection has been available for sometime (Ref. 5), there has been no data in regard to the flow of solid waste slurries. In order to obtain the necessary information on the feasibility of slurry transport of municipal solid wastes an experimental set up was constructed and adequate data on energy losses was collected. The purpose of this paper is to report and discuss the results of these tests. A method of estimating the energy losses will also be presented.

2. EXPERIMENTATION

2.1. Experimental facilities - Fig. 3 shows schematically the experimental set-up. It consists of three 80 feet test sections of 2, 4 and 6 inch diameter galvanized pipes. The materials to be tested, in original form were introduced to a Wescon pulper and then were passed through a Dorr-Oliver Gorator for size reduction. The shredded materials were then brought up to test consistencies by addition of the proper amount of water and pumped through the test pipes at different velocities.

Pressure losses were measured at the initial stage of testing by simple manometers. However, the clogging of manometer lines necessitated the modification of the pressure measuring instrument. Therefore, a positive surge "pressure cell" device shown in Fig. 4 was then installed. The continuous bleeding of "pressure cell" lines eliminated the clogging problem.

Pre-sizing the solid waste presented a difficult problem. The extreme heterogeneity of waste in regard to density, size and its other physical characteristics excludes the use of a single size-reduction process for effective and efficient pre-sizing operations. A preliminary investigation of available shredders indicated that: "It is the policy of most manufacturers of crushing equipment to carefully match the machine used to crush a particular material to the material being crushed, so that efficient crushing will result. Since refuse contains samples of all kinds of materials, few, if any, machines are available which will completely break up unsorted trash. The hammermill seems to be the crusher best adapted to the crushing of refuse. Because it combines shear, tension and compression in the fracturing process, it can break up a wide range of materials. It can also be designed to expel large dense ductile objects such as bolts and pipe fittings, thereby preventing destruction or jamming of the machine. It may be necessary to employ a two stage crushing process or to use a closed loop system in order to end up with a particle size which is small enough to be carried in a water slurry." (Ref. 6)

To establish whether solid waste can be pre-sized, as a preliminary step for slurry transport in pipelines, a combination of a pulper (Wescon pulper) and a positive shear unit (Dorr-Oliver Gorator) were installed in series prior to the mixing tank (see Fig. 3). The purpose of such an installation was to determine whether it is possible to pre-size solid waste. The efficiency was not a significant criterion.

2.2. Materials - Pressure loss data was collected for each major component of solid waste: paper, glass, rags, metals, woods and garbage separately and also for a synthesized mix with the composition of an average solid waste in the United States (see Table I). In addition, head loss data for 1) a solid waste mix which was generated in the center city of Philadelphia (in July) and 2) ashes produced in the city's incinerator were obtained. Table II shows the material and the range of variables tested.

2.3. Procedure - In tests of series I (see Table II) both raw solid waste as delivered by truck from center city of Philadelphia and ashes from the center of the city processed through a hammermill prior to making slurry in the mixing chamber (see Fig. 3). Data was collected for series I tests using simple manometers. In series II however, the material in original form was fed into the pulper-Gorator combination and then passed through the system. Data was collected on series II tests using pressure cells.

3. PRE-SIZING OPERATION

In tests of series I the hammermill proved to be capable of pre-sizing the raw solid waste but required considerable maintenance. The size reduction of the material in series II was accomplished more or less successfully in the Pulper-Gorator combination unit. While, as a result of these tests, it is possible to claim that sufficient size reduction of solid wastes for pipe transport is possible, it should be added that a more efficient system has to be developed for a prototype system. Study along this line is in progress. Table III provides some interesting information in regard to the operation of the pre-sizing unit.

4. RESULTS AND DISCUSSION

Fig. 5 depicts the raw solid waste before and after pre-sizing. Table IV shows the pressure loss data for all the material tested. Particular problems associated with testings are described briefly in Table II. Figs. 6, 7 and 8 show some interesting comparisons. Fig. 6 compares the data for the same material but for different pipe diameters. Fig. 7 shows concentration effects, and Fig. 8 depicts the head loss-velocity relationships for major components of solid waste and the average mix.

It is interesting to note that in Fig. 7 beyond 7 percent solid waste concentration, the pressure losses are almost independent of average velocity. For the tests of series I, based on limited data, this interesting behavior was contributed to the faulty pressure measuring device (Ref. 1). At the time it was thought that the clogging of manometer lines was responsible for this observation. However, present data, with a modified pressure measuring system clearly points out that the phenomenon is intrinsic to the suspension at high concentration. The explanation may rest on the fact that at high concentration the solid waste slurry forms a stable suspension . as can be seen from Fig. 9 , and the slurry moves through the pipe in the form of a plug. This plug flow is observed previously in the slurry of paper stocks. It seems that paper and other fibrous material form a matrix which holds onto the heavy components of solid waste. The gross behavior of this matrix is very similar to slurry formed from only the paper portion of solid waste. Fig. 10 shows the pressure losses for different concentrations of solid waste as compared with the pressure losses resulted from slurry flow of paper alone at the equivalent paper concentrations. It is interesting to note that in all cases the head losses associated with paper slurry alone is almost equal to solid waste slurry having the equivalent paper concentration. For instance, one may observe that a slurry of 10 percent solid waste which contains 55 percent paper produces pressure losses which are slightly higher than a slurry of 5.5 percent paper alone. This observation forms the basis of a method of prediction of pressure losses of solid waste slurries which will be discussed later.

Observation of Fig. 9 also reveals another important property of solid waste slurry which relates to the ease of settling of heavier objects. Since the matrix of fibrous material supports heavier objects, the danger of clogging the pipe due to the sedimentation of solids at low velocities is quite small. During the operation of the experimental lines, it was observed that the start of a line after 24 hours shut off can be accomplished without difficulty. This implies that the designer should not be as concerned with critical velocity as he must be for transport of discrete suspensions (such as coal slurry).

It is important to note that during the tests, certain amounts of air were entered from mixing chamber into pipelines. No attempt was made to stop this. It was felt that it is inevitable that due to the decomposition of the organic portion of solid waste a certain amount of gases will be produced in the line and therefore, it will be more realistic not to bleed the pipes.

5. ESTIMATING PRESSURE LOSSES

Observation of Fig. 10 suggests a method of prediction of the pressure losses of solid waste slurries, *a priori*, from the knowledge of the pipe diameter, concentration of suspension and mean velocity.

The method simply relies on the ability to predict the pressure losses associated with flow of paper slurries. Then, the pressure loss of a solid waste slurry may be predicted by estimating the pressure loss which may be expected from a paper slurry with concentration equal to the concentration that paper component of the solid waste produces. Therefore, the problem becomes one of the prediction of pressure losses for paper slurries.

5.1. Literature Review - The transportation of solids suspended in a liquid medium is a unit operation utilized widely in the chemical process industries. Of these industries, the paper and pulp industry ranks high in terms of the volume of material handled. Because of the wide divergence in the properties of pulp stock as well as variations that occur during transport of a given stock there has been little work of general nature in this field. Pulping practices are always changing, as do mill practices, with the result that pulp properties are changed and prior experimental results are rendered obsolete.

Several investigators have gathered data of pressure losses (Ref. 7 to 12). However, since, in most cases, only a few variables of the system were measured any comparisons of data is difficult. Of the experimental data gathered in this period, the most quoted is Brecht and Heller (Ref. 7). The correlations developed from much of this early work were as widely variant as the data itself.

Since 1952, studies have been reported in both the U.S. and Japan on developing prediction equations. These works have been carried out, in the main, at the University of Maine, and the Tokyo Institute of Technology.

The work carried out at the University of Maine was reported initially by Durst (Ref. 13) in 1952. This paper presented an analysis of the Brecht and Heller (Ref. 7) data, the Forrest and Grierson (Ref. 8, 9) data and the Cameron data (Ref. 10). The relationship which was developed was found to hold in certain ranges of consistency and velocity but deviated sharply outside these ranges. It was shown that different types of stock could account for these discrepancies. In 1954, Durst and Jenness (Ref. 14) published a paper which dealt strictly with bleached sulphite pulp. A correlation between friction factor and the shear values of the stock - a property that can be measured with a laboratory instrument, was proposed. Durst and Jenness suggested a Suspension Flow Number, $N_{SF} = DV\rho/S$ which may be used for suspension flow as the Reynold's number is used for single fluids to predict friction factors. S is shear value, D is pipe diameter, V is mean velocity and ρ is the density of suspension. In a following paper, (Ref. 15) Durst and Jenness extended their analysis to Soda Kraft and Groundwood pulp slurries.

In a more recent paper Head and Durst (Ref. 16) considered the effects of fiber-length; the yield stress of paperstock, and its viscosity on friction factor. It was found that yield stress was an important factor in the correlation. A kinematic equivalent to yield stress, obtained by dividing the yield stress by the density, and whose square root is designated m (m value is constant at any particular concentration), was found to be important in the correlation. The correlation of data led to the conclusion that the friction factor, f, is the product of two factors: a velocity factor f_v which depends on V/m and a slurry factor f_λ which depends on $\ell m/\gamma$ in place of the Reynolds number and $D^2/\lambda K$ as the roughness ratio. λ is the fiber length (measured experimentally) and γ is the kinematic viscosity. Head and Durst suggested the following equation for prediction of head losses:

$$h_f = (9.2)\ 4f_\lambda\, f_v\, m^2\ (L/D) \qquad (1)$$

The primary difficulty in using this equation lies in the determination of m in the laboratory, and the somewhat tedious task of continuous use of graphs for estimating f_v and f_λ.

Riegel (Ref. 17), using the data generated at the University of Maine, and attempting to eliminate the need for a graphical prediction of f_λ and f_v, suggested the following equation:

$$h_f = 9.15\ \frac{Q^{0.364}C^{1.89}K}{D^{2.06}} \qquad (2)$$

where Q is volumetric suspension flow in gallons per minute, C is concentration in percent by weight, D is inside pipe diameter in inches, and K is called the stock factor and is a property of the stock. Equation (2) predicts, without serious error, the head losses of paper stock and pulp flow when the concentration is between 2 to 6 percent, and velocity ranges from 1 to 10 feet per second. Also included in the paper is a nomograph for simple conversion of head losses from one combination of pipe diameter, flow rate, or consistency to any other state of these variables.

A paper by Itaya (Ref. 18) presented data for groundwood pulp up to 6 percent concentration in relatively small (up to 2") pipes. Results were reported in a plot of friction factors versus a dimensionless flow number $N=8\rho V^2/\tau_W$. Where ρ is density, V the mean velocity and τ_W is the shear stress at the wall. The data could be correlated by the equation $f = 64/N$. Using this equation, however, requires trial and error. Tomita (Ref.19) also presented a correlation using a redefined Reynold's number. Little new or usable information was included.

5.2. Prediction Equation - Based on the discussion offered at the outset of Section 5 equation (2) may be used for estimating the pressure losses of the flow of solid waste slurries in pipelines. Factor K is the value associated with assorted paper stock which is found in solid waste, and C is the concentration of the paper component of solid waste in the slurry, and not the concentration of solid waste itself (for instance, the C value for a 10 percent solid waste which contains 55 percent paper is 5.5 percent)

To examine the validity of equation (2) as a prediction equation for solid waste slurry. 1) the data for flows of paper slurries in the 6 inch pipeline was used to ascertain the value of K for assorted papers normally found in solid waste; 2) this value of K was utilized in connection with equation (2) - for different combination of C, Q and D - to predict the pressure gradients which may be expected for solid waste slurries (the values of C, Q, D were selected such that they present the combinations tested during present study), and (3) these predicted values were then compared with experimental values. The comparison was based on the observation that if the predicted value h_f is 100 percent accurate then h_f/h'_f should be equal to 1.00. Where h'_f is the experimentally determined pressure loss and h_f is calculated from equation (2). However, since the present state of the art of two phase flow is such that even for solid-liquid slurries of discrete particles, such as coal and sand slurries, ± 40 percent accuracy is acceptable (Ref. 20) therefore, h_f/h'_f may vary between 0.6 and 1.4 and the prediction equation may still be considered useful. Examination of the valves of h_f/h'_f for all solid waste data obtained in the present study, (data points) indicates that should equation (2) with K=0.446 (which is found from paper data) be used for prediction, there is a 90 percent probability that the predicted value will be within the accepted limits. On the other hand, this implies that there is a 10 percent probability that the predicted value will be either smaller or larger than the acceptable bounds. However, it was also found that the average value of h_f/h'_f for all data points is 1.1. Therefore it is more likely that the prediction will be conservative. As a matter of fact the probability of predicting values less than 60 percent of experimental values is only 1.2 percent. Consequently, it may be concluded that equation (2) can be used for the prediction of pressure losses of solid waste slurry and the results will be within the limits of accuracy for prediction of most other solid-liquid systems.

For the purpose of design the engineer may use equation (2) with K = 0.446 to predict h_f and increase it by 50 percent to be sure that his design will be conservative. To simplify the calculation, a nomograph for solving equation (2) is presented in Fig. 11. The nomograph is self explanatory. It should be noted that head loss for one condition has to be known in order to use nomograph in Fig. 11. This value can be taken from the example given in Fig. 11 or calculated from equation (2).

Conclusion - Based on experimental work reported here it has been shown that 1) in general, the pre-sizing of domestic solid waste with equipment available on the market is possible, though for attaining high efficiency new designs are needed; 2) pumping solid waste slurries up to 12 percent concentration by weight through pipes is feasible; and 3) the pressure losses may be calculated with an equation developed for paper slurry with a modified parameter.

Acknowledgment - The work reported in this paper was supported by U.S. Public Health Service Research Grant EC00259-04. The assistance of Mr. D. Farivar and Mr. N. Yanagida to collect data and draw the figures is acknowledged with many thanks. Wescon and Dorr-Oliver have kindly donated the Pulper and Gorator respectively for this study.

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TABLE I - MAJOR COMPONENTS OF SOLID WASTES:

Investigators	Reference	Major Components in % by Weight										Observations:
		Paper	Glass	Sand & Dirt	Ashes	Metal	Food Waste (garb)	Wood	Rags	Yard Trim-ming	Misc. (Plas., Rubber, Leath., Etc.)	
A.P.W.A.	21	60.0	8.5	0.5	-	8.0	8.5	-	0.5	6.5	8.0	
Golueke, C. G. & McGauhey, P.H.	22	50.0	7.0	2.3	0.7	8.0	12.0	2.0	2.0	9.0	7.0	
A.C.S.	23	56.0	10.0	10.0	-	8.0	12.0	7.0	3.0	-	4.0	Dirt includes ashes
Rogus, C. A.	24	56.5	-	-	18.7	14.8	4.8	-	-	9.6	-	
Aerojet General	25	54.0	3.0	5.0	-	7.0	15.0	1.0	2.0	10.0	2.0	Dirt includes ashes
Anonymous	26	42.0	6.0	-	10.0	8.0	22.5	-	-	-	11.5	
Kaiser, E.	27	42.0	6.0	4.5	10.0	8.0	12.0	-	0.6	12.0	2.7	
President's Science Advisory Commis-sion	28	45.0	6.0	-	10.0	8.0	12.0	-	-	15.0	4.0	
Hoffman, D. A.	29	46.1	8.3	-	-	7.7	0.8	7.5	3.5	21.1	5.0	
Hickman, H., Lanier, J., and Kemedy, J. C.	30	47.0	5.0	-	-	9.0	31.0	4.0	2.0	-	2.0	
Purdom, P. W., Schoenberger, R., Michaels, A. & Bergsten, A.	31	54.5	8.5	-	16.4	8.4	5.0	2.4	2.6	-	2.3	Ashes includes the dirt
Synthetic Solid Waste		55.0	8.0	8.0	8.0	8.0	10.5	0.5	0.5	2.0	1.0	See Below*

*No grass and yard trimmings were available in large quantities so hay was used as a replacement in laboratory tests. Shavings of steel were used as the metallic portion of solid waste. Food waste was simulated by using fresh food stuffs to limit disease hazard.

TABLE II - MATERIAL AND RANGES OF VARIABLES TESTED

Series	Material	Description		Pipe Diameter in. Range of velocity, fps ( ) Range of Concen., % *	Observations
		Before Pre-sizing	After Pre-sizing		
I	Raw solid waste from City of Philadelphia trucks (July)	Mixed waste of all kinds, representative of one truck's daily collection	Small Uniformly mixed pieces of waste. Crushed finely enough so that individual identification of material was difficult	2, 4, 6 (1-15) 0-11	Little difficulty was experienced in pumping this slurry. Limit of 11% was because difficulties in mixing the slurry uniformly and problems with keeping manometers clean. Also upper limit of available pump head was being approached.
	Residue from City of Philadelphia incinerator (July)	Primarily ashes, with many unburned items such as wire, pieces of metal, etc.	Ash in a more powderized form. Unburned items crushed to a small size.	2, 4, 6 (1-15) 0-6	No problems was encountered in this series of tests
II	Paper	Newspaper, Cardboard	Fine, Pulped Paper	—, 4, 6** (1-15) 0-5.5	Extreme thickness of slurry at 5.5% forced tests to be discontinued.
	Glass	Bottles	Jagged particles up to 1/2" size distance	2, 4, 6 (1-15) 0-20	No problem
	Steel	———	Steel was obtained in shredded shavings ?	2, 4, 6 (1-15)	No problem

TABLE II - CONTINUED

Series	Material	Description		Pipe Diameter in., Range of Velocity fps ( ) Range of Concen., % *	Observations
		Before Pre-sizing	After Pre-sizing		
II	Sand	Fine Washed Sand	No Change	2, 4, 6 (1-15) 0-20	No problem
	Ashes	Fly Ash and Cinders	No Change	2, 4, 6 (1-15) 0-16	No problem
	Hay	Animal Feed quality	Small pieces of shredded hay	2, 4, 6 (1-15) 0-3	Clogging of 2" & 4" pipes forced the stoppage of data taking in those diameter pipes.
	Food Stuffs	Meat, Fat, Vegetables and Fruit	Conglomeration of small bits of food waste	2, 4, 6 (1-15) 0-18	Flow was fluctuating too badly to take data in 2" line (Reason Unknown)
	Wood Chips	Approximately 1"X2" Pieces	Size reduced to approximately 1/2"x 1"	- - - - - - - - -	Wood chips formed barrier behind valves clogging them so that no data could be taken
	Synthetic Solid Waste	Mixture of all Series II items	Mixture of all Series II items	-, 4, 6** (1-15) 0-10	No problem of any serious nature was encountered.

* Percent by weight implies 100 W_s/W_w, where W_s is the weight of solids and W_w is the weight of water It should be noted that only in the case of food stuffs this value is noticeably different than true solid concentrations because of water content of waste.

** No data was taken for 2" pipe because the manifold clogged at 2" connection.

Table III - Performance of Pulper-Gorator Unit

Material	Observation
Paper	Paper was handled by the equipment with no trouble whatsoever as long as it was not fed in batches exceeding 15 lbs. One 25 lb. batch was fed in purposely and the machine did not shred any of it. This very likely was due to the small size of the laboratory unit and the low horsepower which was available. It also should be noted that the strings wrapping the paper bundles were not cut at all.
Glass	In strictly glass crushing the Gorator over-heated, and appeared on the verge of seizing up. The Pulper had no apparent problems.
Hay	Hay was handled by the unit with little difficulty.
Rags	The pulper simply would not shred rags unless given excessively long time. If one rag was fed every 60 seconds at the end of 10 minutes or so a mass of rags would be formed from the separate ones. No effective shredding could be accomplished. Thus use of the unit was not practical and testings of rags alone discontinued.
Steel Shavings	The steel obtained was in the form of small chunks and shavings, therefore, it was not intoruduced into the presizing unit. In the case of tin cans, limited testing was done with moderate success.
Wood Chips	Wood chips were handled by the pre-sizing units with no difficulty at all. This perhaps was due to the relatively small size of the chips to begin with. Larger pieces of wood were not tested on the manufacturers recommendation. It was thought that the horse-power of present unit was unsufficient.
Organic Materials (Food Stuffs)	No difficulty was encountered in shredding the following materials: Meat, fat, bones, corn (husks), and all vegetables and fruits. Some large, round, skinned items, such as a watermelon, sit on the rotor's blade without projecting into the cutting plane. Therefore, these items were not crushed for long periods of time.
Synthetic Solid-Waste	(Mixtures of above materials plus sand and ashes) - There seem to be very little difficulty in shredding this composite. Apparently having more than one type of substance being processed improves the performance of the pre-sizing unit. The materials which had been difficult to crush alone shredded rather easily.

Table IV - Head Loss Data, ft/ft (Feet of water per foot of Pipe)

Material	Values in Parentheses Indicate Velocity in ft/ sec.																		
Pipe Diameter →	6 Inches							4 Inches							2 Inches				
Concentration in percent 100 W_s/W_w →	2	4	6	7	8	9	10	2	4	6	7	8	9	10	2	4	6	7	8
Synthetic Solid Waste	.015 (3.7)	.017 (3.3)	.057 (2.8)	.092 (2.0)	.128 (2.0)	.163 (2.1)	.191 (2.0)	.025 (6.4)	.031 (3.4)	.083 (2.7)	.117 (2.9)	.179 (2.1)	.238 (3.0)	-	.027 (2.9)	-	-	-	-
	.019 (5.3)	.021 (4.1)	.058 (3.7)	.091 (2.5)	.126 (3.6)	.182 (2.9)	.208 (3.2)	.043 (8.2)	.039 (4.9)	.085 (4.6)	.119 (4.6)	.178 (4.4)	.244 (4.6)	-	.052 (5.8)	-	-	-	-
	.076 (13.2)	.056 (11.2)	.093 (10.6)	.092 (5.2)	.128 (5.2)	.177 (3.1)	.208 (3.7)	.054 (9.7)	.149 (15.5)	.178 (15.2)	.167 (10.3)	.194 (9.7)	.270 (10.6)	-	.163 (11.1)	-	-	-	-
Concentration	2	4	4.3	5	5.5	-	-	2	-	-	-	-	-	-	2	-	-	-	-
Paper	.019 (2.6)	.105 (2.4)	.140 (2.7)	.167 (1.6)	.214 (2.0)	-	-	.028 (2.6)	-	-	-	-	-	-	.095 (7.6)	-	-	-	-
	.024 (3.5)	.110 (3.8)	.133 (4.0)	.181 (2.3)	.204 (2.7)	-	-	.031 (3.3)	-	-	-	-	-	-	.150 (10.5)	-	-	-	-
	.053 (10.1)	.134 (6.6)	.137 (5.9)	.199 (3.9)	.232 (3.3)	-	-	.081 (11.3)	-	-	-	-	-	-	.192 (14.5)	-	-	-	-
Concentration	1	2	3	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
Hay	.013 (3.2)	.016 (1.8)	.025 (2.3)	-	-	-	-	.019 (3.7)	-	-	-	-	-	-	.101 (5.8)	-	-	-	-
	.015 (3.9)	.022 (2.7)	.023 (3.7)	-	-	-	-	.027 (6.1)	-	-	-	-	-	-	.125 (7.6)	-	-	-	-
	.023 (5.3)	.032 (7.0)	.024 (4.7)	-	-	-	-	.050 (8.1)	-	-	-	-	-	-	.168 (8.1)	-	-	-	-
Concentration	2	4	8	12	14	16	20	2	4	6	8	10	15	18	2	4	8	16	22
Glass	.008 (3.5)	.007 (3.9)	.012 (3.6)	.013 (3.6)	.018 (5.9)	.020 (3.9)	.015 (3.2)	.012 (3.7)	.014 (3.7)	.005 (2.1)	.022 (4.0)	.029 (4.4)	.057 (8.2)	.086 (9.1)	.043 (3.5)	.069 (2.3)	.058 (2.3)	.025 (2.9)	.050 (4.7)

Table IV - Head Loss Data, ft/ft (continued)

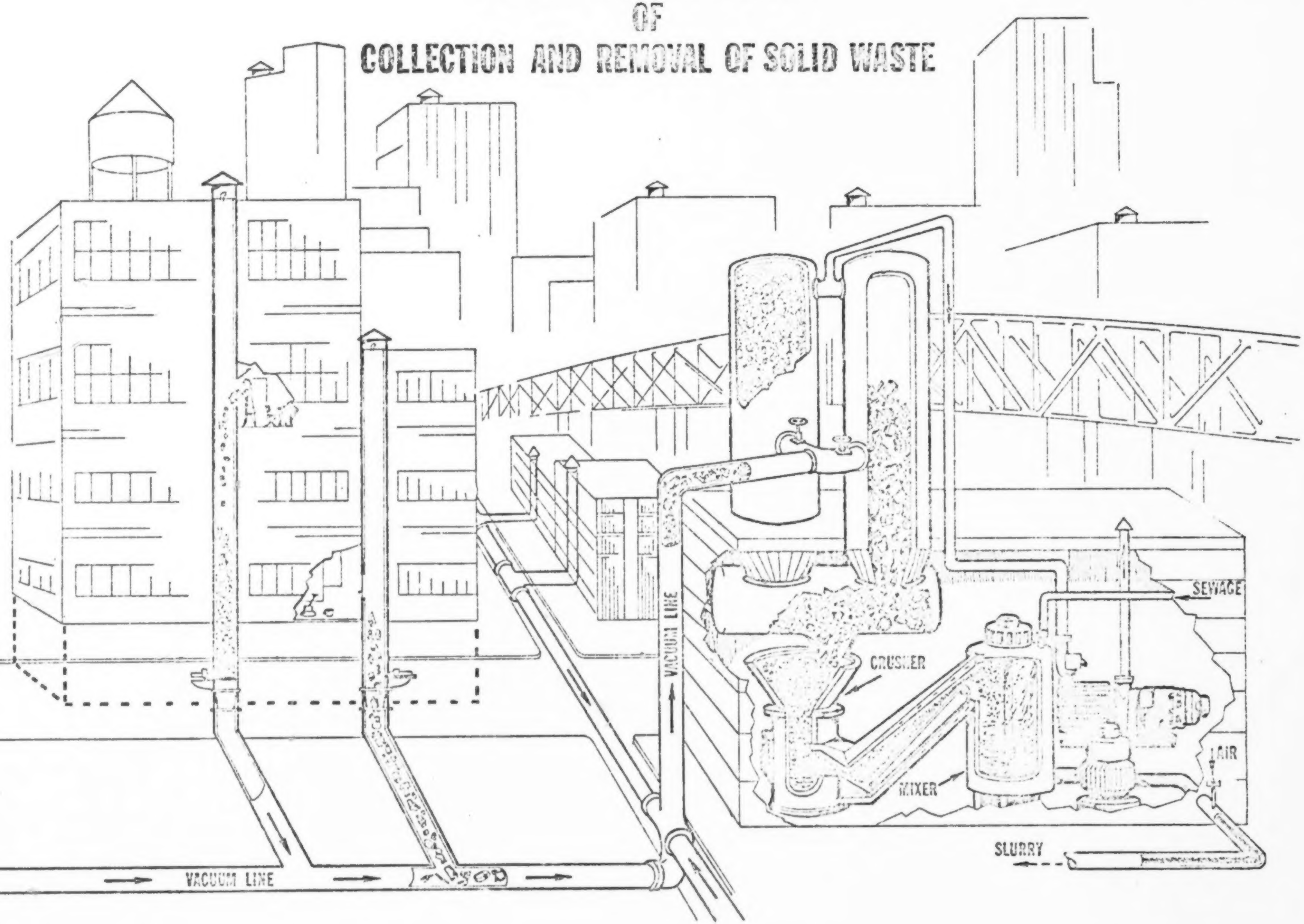
Material	Values in Parentheses Indicate Velocity in ft/sec																		
Pipe Diameter	6 Inches							4 Inches							2 Inches				
Concentration	2	4	8	12	14	16	20	2	4	6	8	10	16	18	2	4	8	16	22
Glass	.013 (5.2) .052 (8.5)	.013 (4.9) .054 (9.7)	.017 (5.6) .076 (12.0)	.029 (6.3) .064 (10.8)	.038 (7.6) .048 (9.6)	.030 (6.1) .063 (10.5)	.040 (5.9) .107 (13.3)	.023 (5.8) .179 (15.5)	.032 (5.5) .202 (15.8)	.036 (6.2) .079 (9.7)	.023 (4.6) .151 (15.1)	.047 (6.5) .159 (13.4)	.074 (9.3) .166 (13.9)	.115 (11.1) .139 (13.4)	.100 (7.0) .220 (10.5)	.111 (3.5) .265 (9.3)	.072 (3.5) .268 (9.9)	.043 (4.1) .173 (9.3)	.080 (5.8) .253 (11.6)
Concentration	2	4	8	12	14	16	20	2	4	8	12	14	16	20	4	8	12	16	20
Sand	.012 (4.7) .033 (7.9) .074 (11.9)	.013 (5.3) .028 (7.9) .086 (12.9)	.013 (5.1) .025 (7.5) .077 (12.9)	.016 (4.9) .027 (7.6) .092 (13.3)	- - -	.021 (4.6) .040 (8.6) .084 (13.1)	.021 (4.3) .043 (8.2) .082 (12.5)	.012 (2.9) .057 (7.9) .140 (12.9)	.013 (4.1) .071 (9.6) .171 (15.8)	.036 (6.5) .048 (7.6) .111 (13.1)	.027 (4.6) .049 (7.3) .099 (11.4)	- - - -	.039 (5.5) .054 (7.9) .158 (15.0)	.042 (4.9) .070 (9.1) .211 (17.0)	.061 (5.8) .082 (7.0) .229 (12.2)	.054 (5.3) .137 (9.3) .168 (10.5)	.028 (3.5) .079 (6.9) .135 (9.3)	.062 (6.4) .138 (9.3) .253 (12.8)	.061 (5.8) .086 (7.6) .265 (12.8)
Concentration	2.7	4	6.7	8	10.7	16	20	2.7	4	6.7	8	10.7	16	20	4	8	10.7	16	20
Ash	.016 (5.9) .023 (6.3) .093 (13.0)	.023 (6.7) .027 (7.6) .085 (13.0)	.013 (5.1) .026 (6.8) .082 (12.0)	.014 (5.4) .026 (6.8) .078 (12.0)	.015 (5.2) .036 (8.1) .083 (12.5)	.015 (5.6) .024 (6.3) .073 (11.7)	- - -	.015 (4.3) .051 (7.9) .137 (13.4)	.011 (3.3) .042 (6.9) .144 (13.4)	.010 (3.3) .033 (6.1) .153 (14.0)	.024 (5.2) .049 (7.3) .165 (15.0)	.025 (5.5) .054 (7.6) .167 (14.3)	.033 (6.4) .071 (9.1) .156 (13.7)	- - -	.048 (4.1) .104 (7.0) .238 (11.6)	.023 (2.3) .074 (5.3) .208 (10.5)	.055 (4.7) .073 (5.3) .256 (11.6)	.048 (4.7) .101 (7.0) .223 (10.5)	- -
Concentration	2	4	-	-	-	-	-	2	4	-	-	-	-	-	-	-	-	-	-
Steel	.007 (3.5) .024 (6.4) .093 (13.3)	.007 (3.6) .019 (6.6) .066 (11.1)	- - -	- - -	- - -	- - -	- - -	.028 (5.3) .048 (7.4) .131 (12.9)	.010 (3.7) .030 (6.5) .147 (14.6)	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -

Table IV - Head Loss Data, ft/ft (continued)

Material	Values in Parentheses Indicate Velocity in ft/ sec.																		
Pipe Diameter	6 Inches							4 Inches							2 Inches				
Concentration, lbs. of material in lbs. of water	3	6	8	10	12	15	18	3	6	8	10	12	15	18	-	-	-	-	-
Organic	.012 (4.5)	.010 (4.5)	.011 (4.5)	.009 (4.2)	.007 (3.5)	.011 (3.9)	.006 (2.7)	.024 (4.9)	.027 (5.8)	.024 (5.2)	.030 (6.7)	.023 (5.2)	.040 (7.0)	.040 (7.4)	-	-	-	-	
	.016 (5.3)	.030 (7.9)	.016 (5.6)	.017 (5.6)	.027 (7.5)	.023 (6.7)	.034 (8.4)	.039 (6.7)	.049 (8.5)	.029 (7.0)	.049 (8.5)	.051 (8.1)	.054 (8.5)	.058 (9.1)	-	-	-	-	
	.070 (12.4)	.072 (12.9)	.086 (13.3)	.065 (11.8)	.067 (11.6)	.042 (9.2)	.068 (11.8)	.106 (13.1)	.123 (14.0)	.107 (12.3)	.178 (17.2)	.165 (16.1)	.158 (15.8)	.125 (14.0)	-	-	-	-	-

Figure 1

PNEUMO-SLURRY SYSTEM OF COLLECTION AND REMOVAL OF SOLID WASTE


VACUUM LINE
VACUUM LINE
SEWAGE
CRUSHER
MIXER
AIR
SLURRY

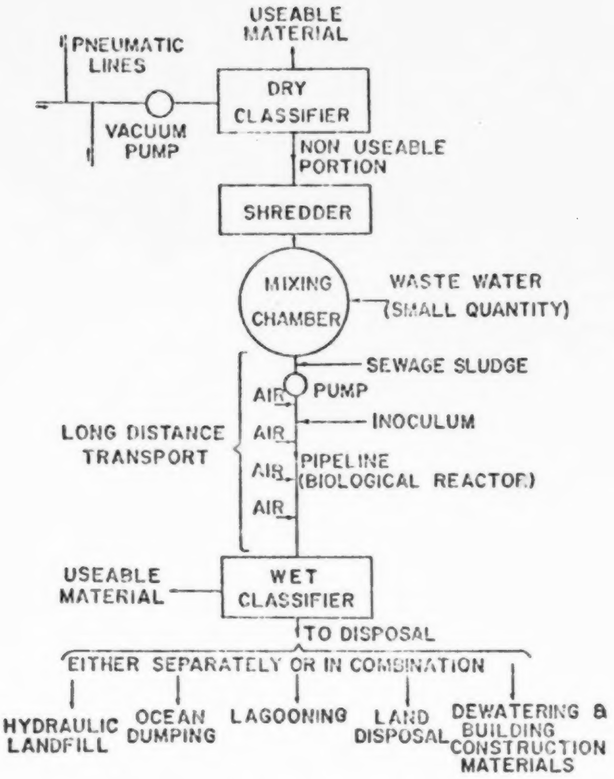

USEABLE MATERIAL
PNEUMATIC LINES
DRY CLASSIFIER
VACUUM PUMP
NON USEABLE PORTION
SHREDDER
MIXING CHAMBER
WASTE WATER (SMALL QUANTITY)
SEWAGE SLUDGE
PUMP
AIR
INOCULUM
LONG DISTANCE TRANSPORT
PIPELINE (BIOLOGICAL REACTOR)
USEABLE MATERIAL
WET CLASSIFIER
TO DISPOSAL
EITHER SEPARATELY OR IN COMBINATION
HYDRAULIC LANDFILL
OCEAN DUMPING
LAGOONING
LAND DISPOSAL
DEWATERING & BUILDING CONSTRUCTION MATERIALS

Fig. 2 - A possible system of collection and disposal of solid waste.

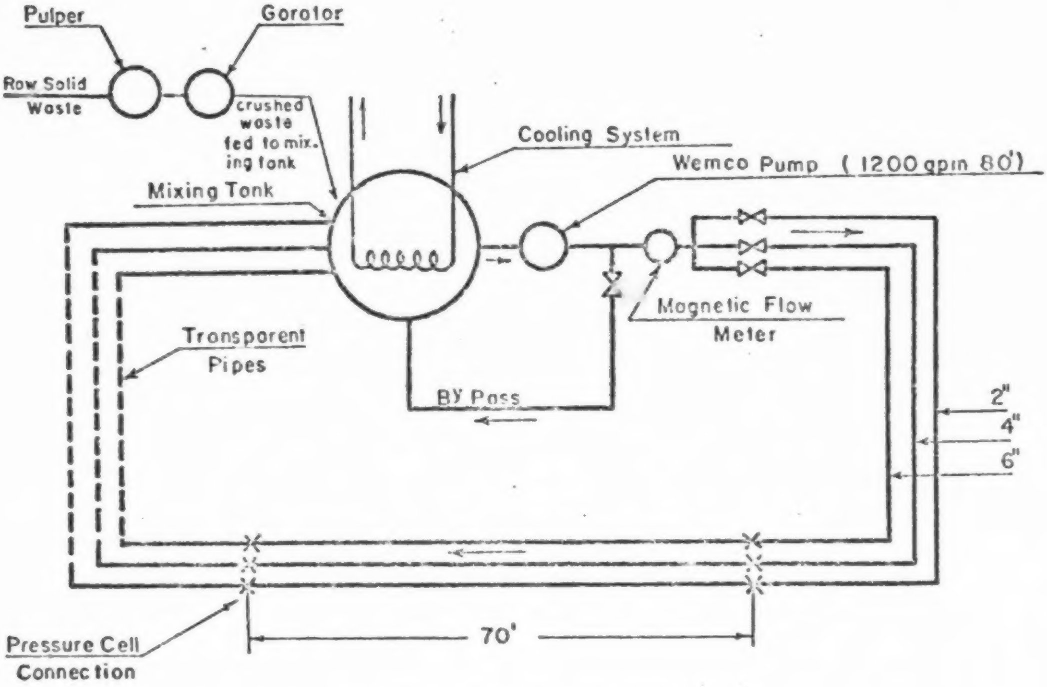

Pulper
Gorotor
Row Solid Woste
crushed woste fed to mixing tonk
Cooling System
Wemco Pump (1200 gpm 80')
Mixing Tonk
Magnetic Flow Meter
Transporent Pipes
BY Poss
2"
4"
6"
70'
Pressure Cell Connection

Fig. 3 - Experimental Set Up

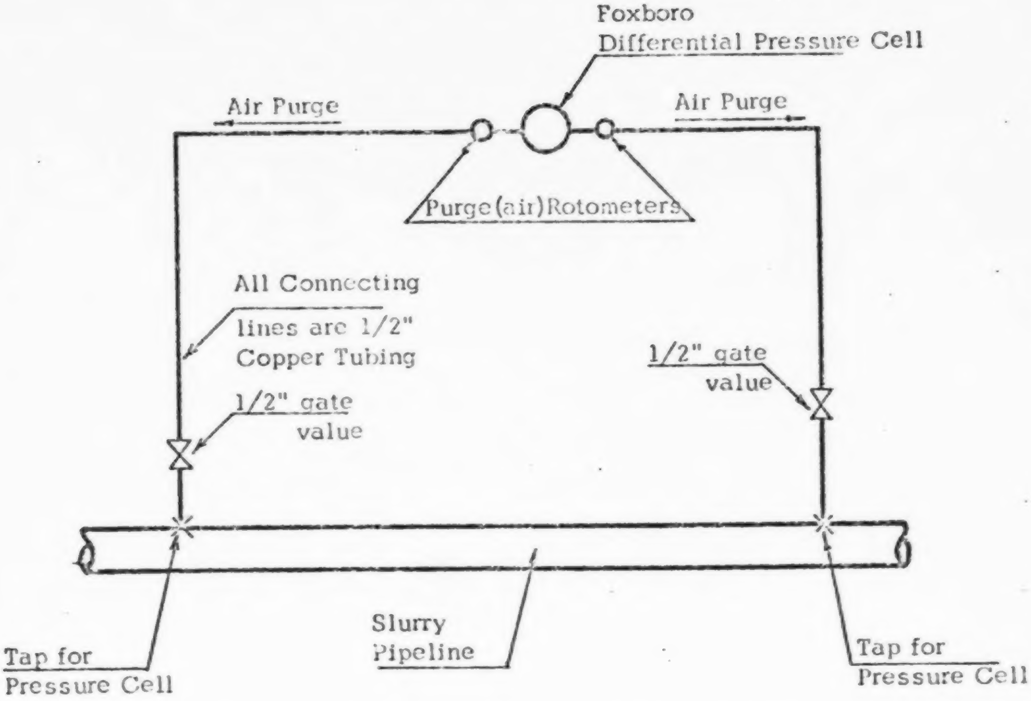

Foxboro
Differential Pressure Cell
Air Purge
Air Purge
Purge (air) Rotometers
All Connecting lines are 1/2" Copper Tubing
1/2" gate value
1/2" gate value
Tap for Pressure Cell
Slurry Pipeline
Tap for Pressure Cell

Figure 4: Schematic Diagram of Pressure Cell

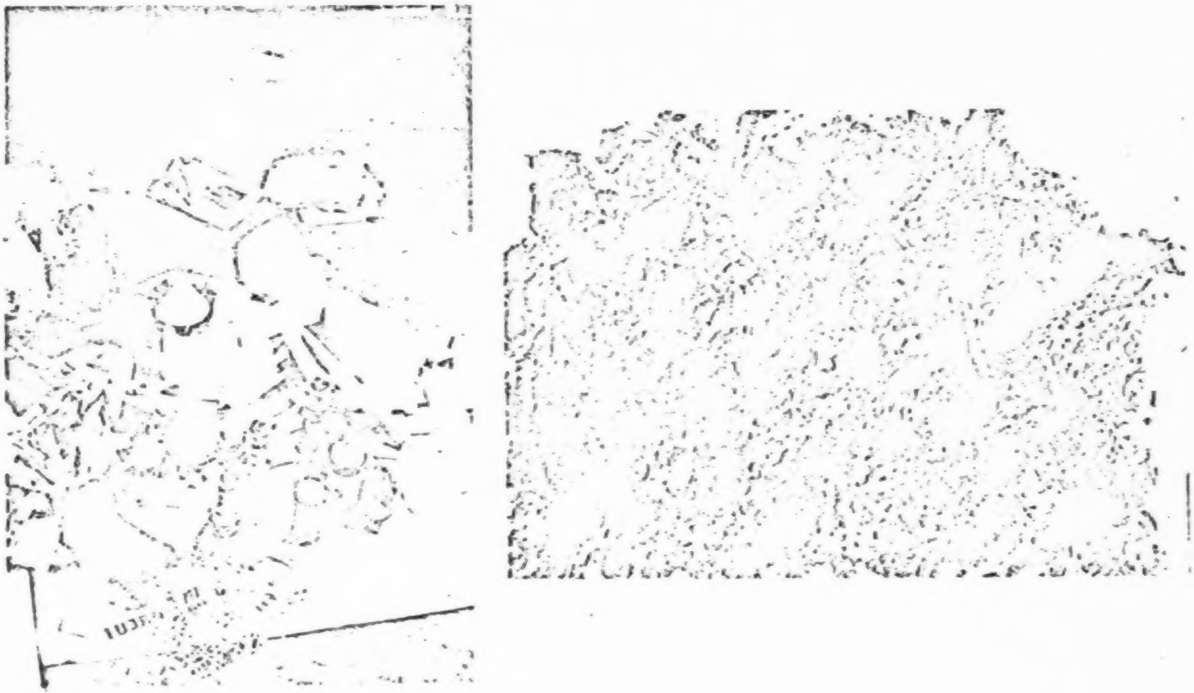


Figure 5 Solid waste before and after passing through Wascon pulper and Gorator

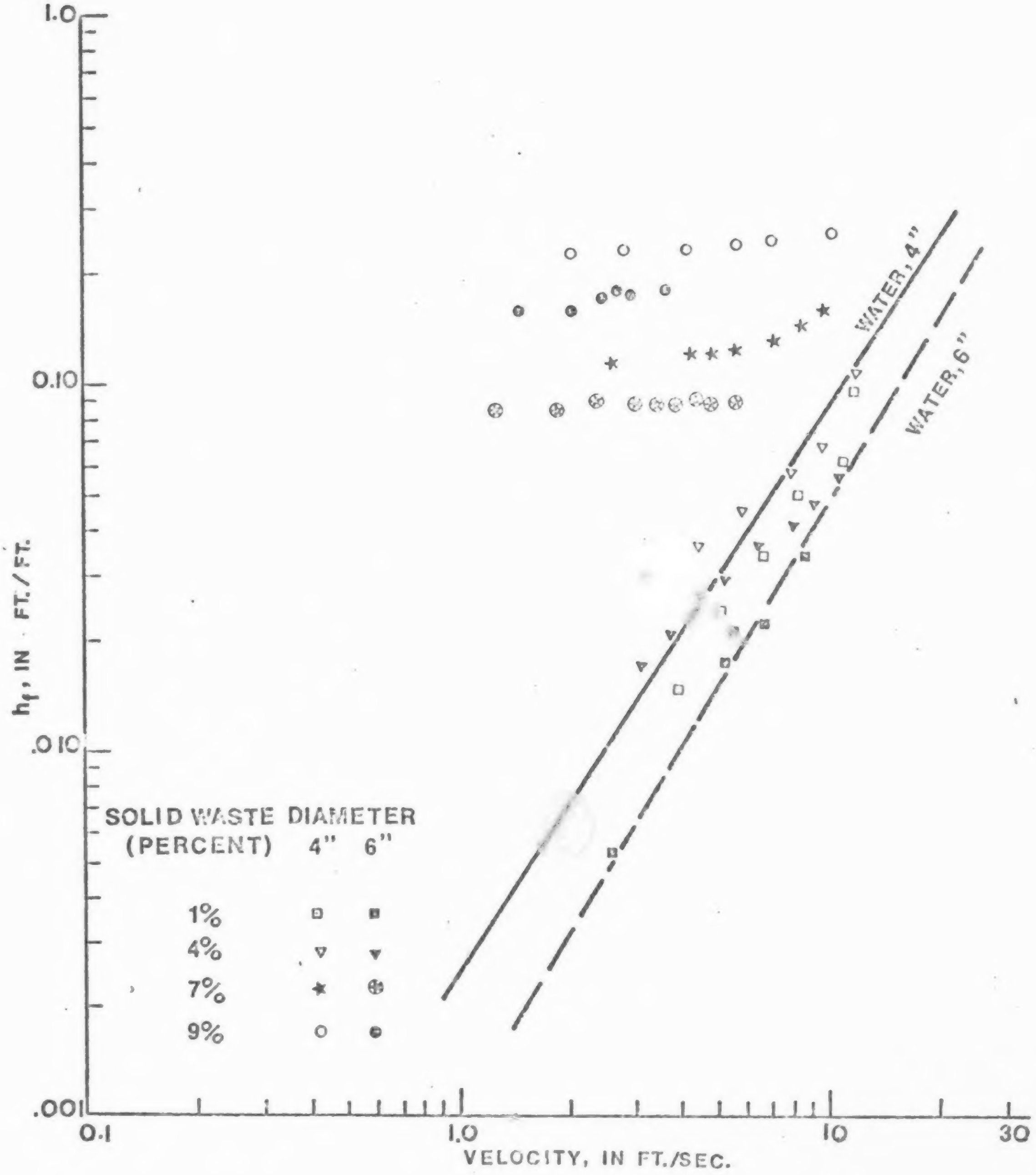


FIG.6- DIAMETER EFFECT, 6" & 4" PIPE.

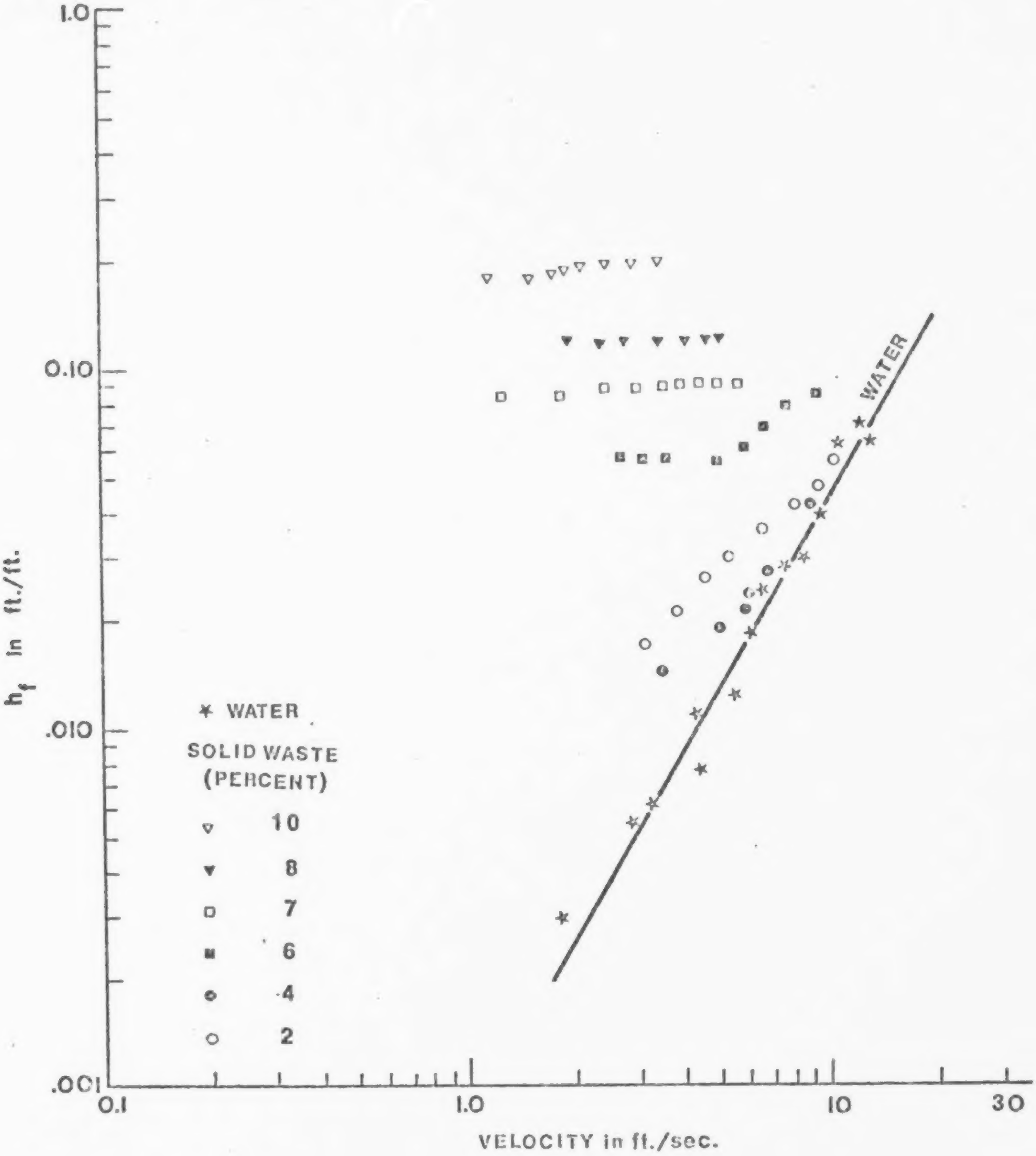


FIG.7- CONCENTRATION EFFECT, 6" PIPE.

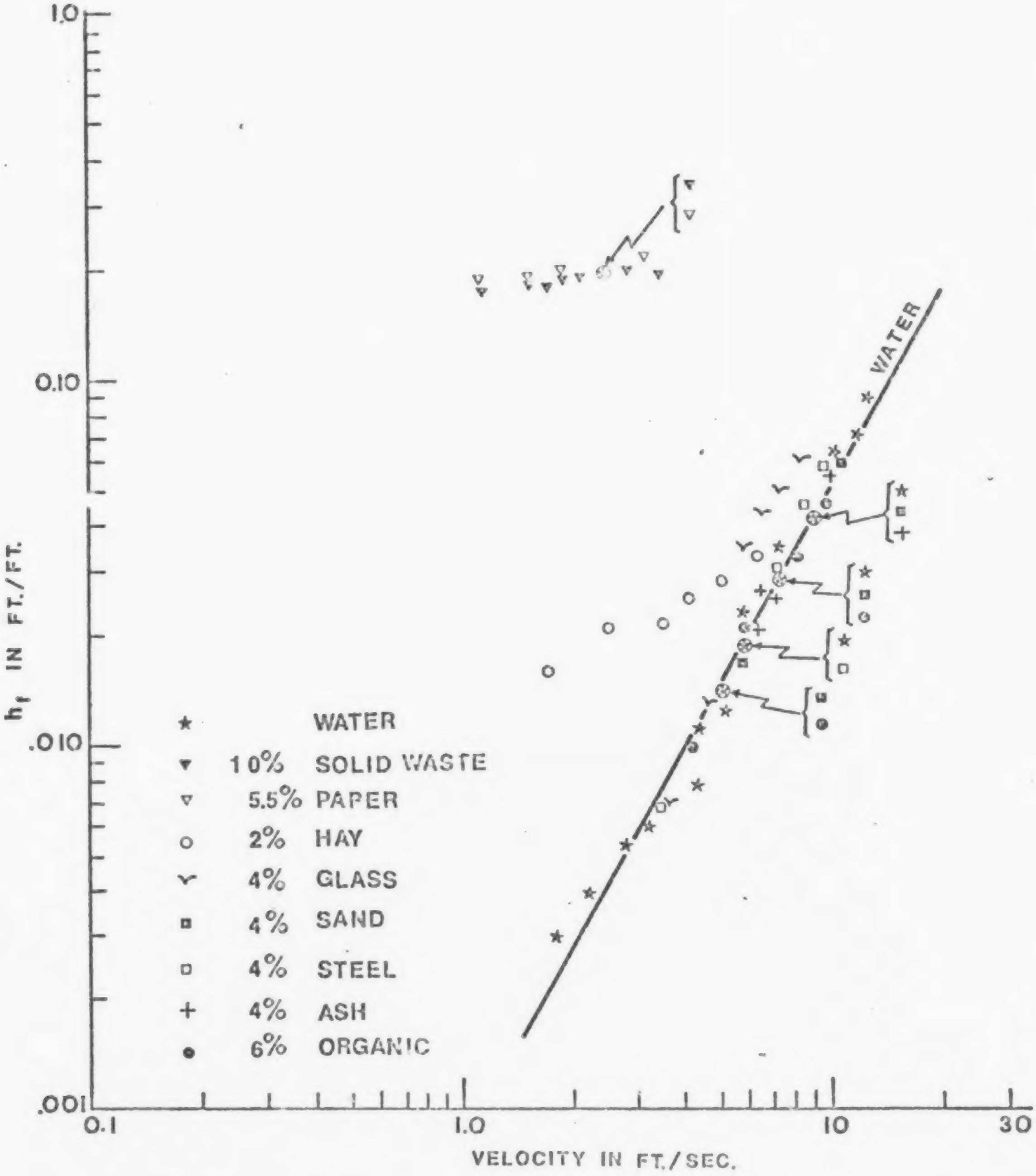


FIG. 8 - MAJOR COMPONENTS OF SOLID WASTE & AVERAGE MIX, 6" PIPE.

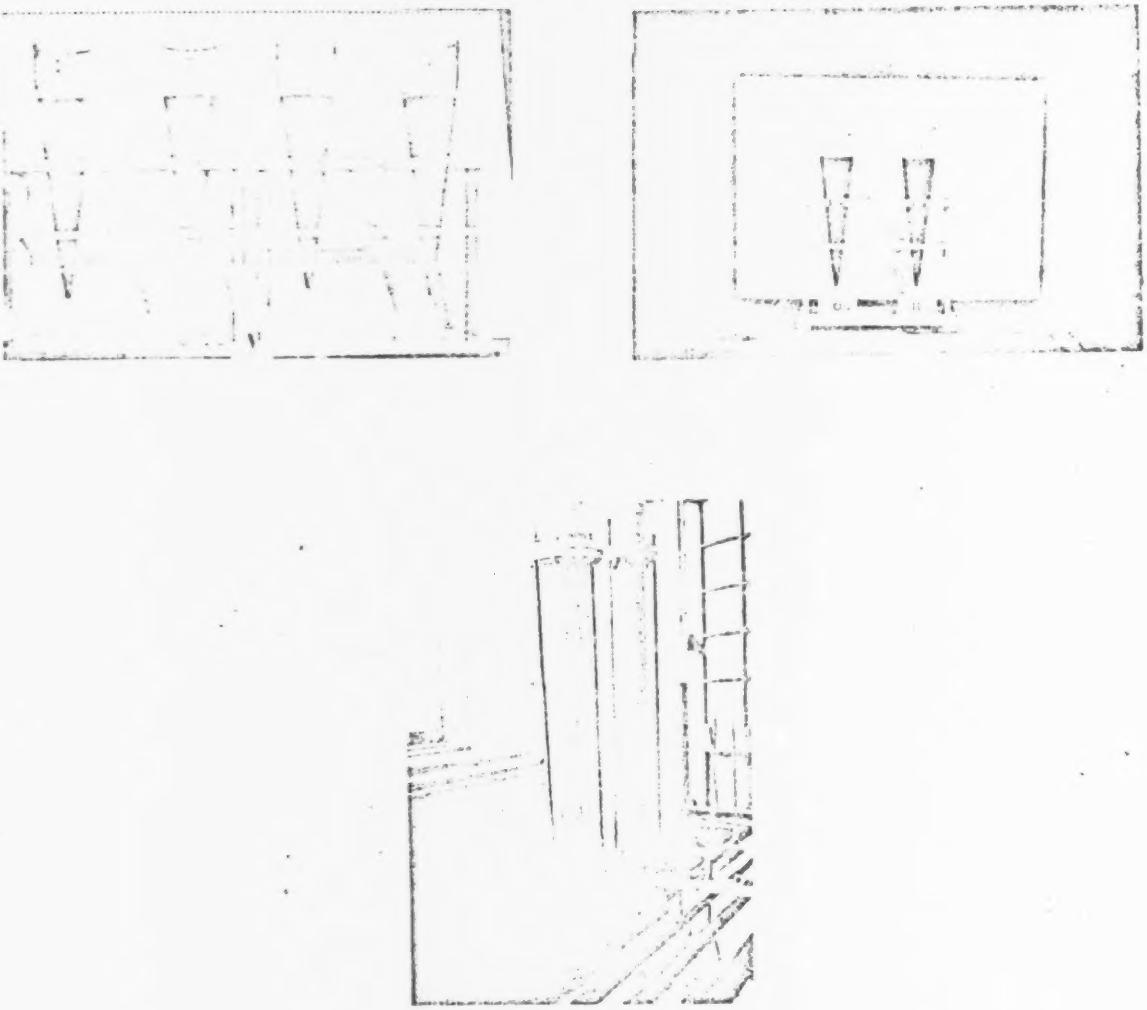


Figure 9 - Solid Waste Slurries

Reproduced from best available copy.

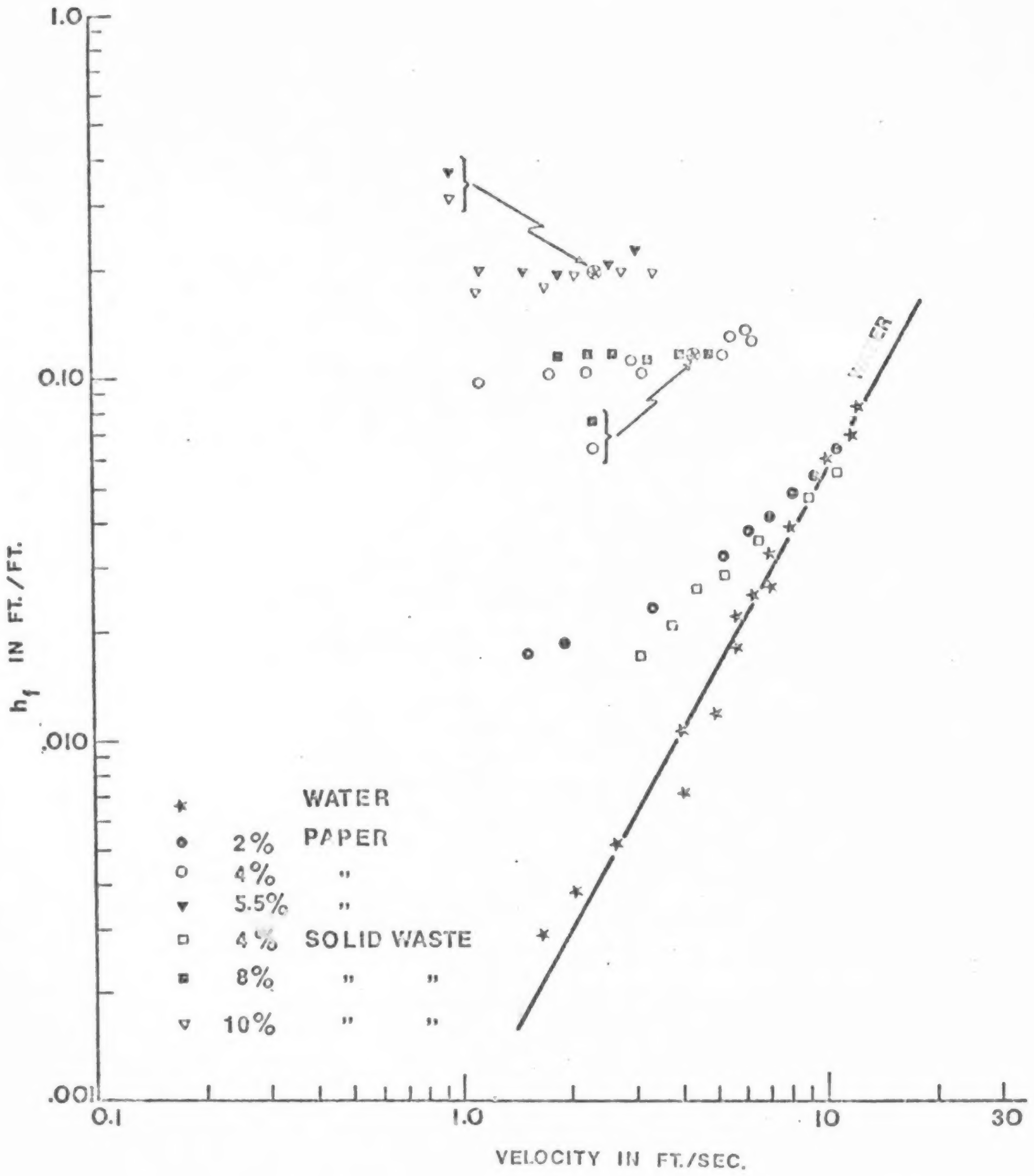
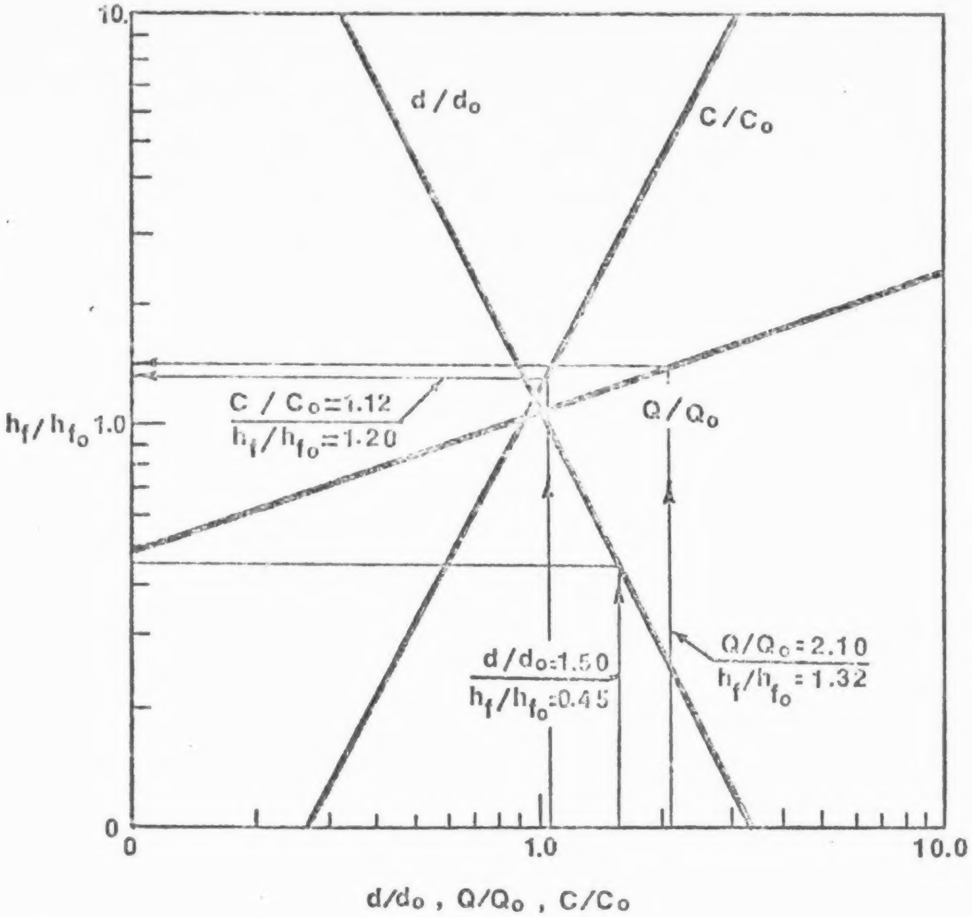


FIG.10 - SOLID WASTE SLURRY (55% PAPER) BEHAVES LIKE ITS PAPER COMPONENT, 6" PIPE.



Example:

Given: Q_o = 84 GPM, C_o' 8% solid slurry (50% paper), D= 4" According to equation (2) h_f = 0.17 ft/ft.

Find: Head loss where:	Solution: Since solid waste concentration is 8% the concentration if the paper component C_o= 4%.
1. only pipe diameter is changed to 6".	1. D/Do = 6/4=1.5→ h/ho=.45 (from graph)→ h =.08
2. only concentration is changed to 9%.	2. Q/Qo=174/84=2.1→ h/ho= 1.4= h =.24
3. Only flow is changed to 174 GPM.	3. C/Co=4.5/4.0=1.12→h/ho= 1.13→ h =.22
4. all three changes occur simultaneously.	4. All h/ho ratios are multiplied to obtain a joint ratic of h/ho= 834→h=.142.

Figure 11 - Nomograph for solid waste pipeline design.

Appendix III

Solid Waste Generation and Cost in Center City of Philadelphia

This material was published by J. A. Hayden, P. Seidenstat, and Iraj Zandi in Environmental Letters, 1, 3, pp. 173-190, 1971.

SOLID WASTE GENERATION AND COST IN THE CORE OF A TYPICAL METROPOLITAN AREA

BY

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ABSTRACT

The efficient management of solid waste collection and removal systems, and the planning for their future development, requires the knowledge of the spacial distribution of solid waste generation in the cities. The statistics, such as per capita generation of solid waste and per ton cost of collection, while provide interesting information, are of little use in the planning of collection systems in the center areas of large metropolis. This is because of the heterogeneity of activities and the significant differences in number of day occupants and night residents. It seems more meaningful, to relate the variables of a solid waste generation system to the size and type of activities occuring in a building. This information, in turn, can be correlated with zoning and land development information for future prediction. Also, in areas where land is already developed, the knowledge of the number and type of buildings can be used in the control of the collection operation.

This paper presents the results of an in depth survey of the process of generation and collection of solid waste in the center city of a typical metropolitan area and relates the data on waste production and collection cost to the type and size of buildings. In addition, information is obtained as to the use of garbage grinders in this center city. An interesting item of information obtained relates to the people's view of the collection process. It was found that almost everybody, for one reason or another is unhappy with the present collection activities.

SOLID WASTE GENERATION AND COST IN THE CORE OF A TYPICAL METROPOLITAN AREA

BY
John A. Hayden[1], Paul Seidenstat[2],
and Iraj Zandi[3]

I. INTRODUCTION

Man's need to deal with solid waste problems and the difficulty of solving those problems have been well documented.(1,2,3,4,5) Before courses of action can be proposed to alleviate the problems of solid wastes, a reasonably accurate data base must be available. Although data relating to the solid waste generation process are gradually becoming available, so far, few in-depth studies have appeared in the literature. The majority of the published studies are concerned primarily with the amount of solid waste generated. Only scattered information relating to costs of collection and disposal exist. Some of these studies use as data sources only municipal or towship estimates of quantities collected by the local governments themselves; (6,7) ignoring privately hired collectors and self-collections. Others base their results on estimates provided by disposal site operators(8,9) despite the fact that in one study it was found that data obtained in this manner constituted only 35% of the total wastes generated in the area.(9) The latest and most complete study to date (1969) is published by the Environmental Control Division of the U.S. Public Health Service.

This work, however, contains only an overall data picture of an area. It does not include detailed analysis for specific individual communities, but rather analyzes data for regions of the country.

The purpose of the present paper is to report the results of an in-depth survey of the characteristics of the solid waste generation of a critical sub-region in any collection

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and disposal plan, the core area of a large city. The paper will present the important information about the study area, discuss the methodology of the survey, relate pertinent findings and analyze the significance of those results. Although the results are directly applicable only to the study area, the investigation was conducted in a manner that the methodology and general conclusions could be applied to similar areas.

II STUDY AREA

CENTRAL CITY PHILADELPHIA AS A WASTE GENERATING SYSTEM

The area studied, as depicted in Fig. 1, was selected because it contains within its boundaries almost all waste generating units which may be expected to be found in an urban community. To aid in the mechanics of the study the area closely coincided with both the 1960 census tracts and a city waste collection route. Table 1 presents relevant data about the study area.

At the beginning of the survey it seemed that the desired data on the variables of quanity and cost might be available from three sources: 1) those who collect solid waste, 2) those who operate disposal facilities or 3) the waste generators themselves. Further study however, elimated the first two possibilities and narrowed the choice to waste generators.

Similar to the situation in most large cities, both city forces and private firms engage in the collection process. While reliable city records are available for its portion of the collection operation, the insufficiency of data is in the province of the private collectors. Most of these companies keep no accurate record of tonnage or volume; they charge for collection by building and pay for disposal by the truck load. In addition, a limited amount of self-collection takes place. These gaps in available records ruled out dependency on collection sources for complete, and accurate data. On the other hand, data provided by disposal sites could not be used because private collectors haul their refuse to land fills out of the state (in the main across the Delaware River to Southern New Jersey). This haulage is made to avoid a disposal charge at city incinerators which is about eight times as large as the charge for land fill. To separate and account for the solid waste of the relatively small study area, utilizing data from these disposal sites, seemed untenable.

Consequently, the decision was made that the waste generators themselves, in terms of real property, should be surveyed. The types of properties found in the study area are listed in Table 2 and are classified by usage. It can be seen that almost all types of residential and commercial properties arerepresented.

III SURVEY METHODOLOGY AND STRATIFICATION OF DATA

In putting together the mechanics of the survey, a decision had to be made as to what information was desired and how it should be obtained. To that end a questionnaire was prepared and in the spring of 1967 a test survey was undertaken to establish its strengths, shortcomings, and work-ability. Preparatory to the test survey, information concerning the properties in the area was obtained from the Finance Department of the City of Philadelphia. Owing to the large number of properties, two thousand questionnaires were mailed. The desire was that a 25 to 50 percent return rate would be experienced and that this number of returns would provide a reasonable sample size. Each individual questionnaire was coded (so that the specific property returning information could be identified). The properties sampled were chosen by using a random number generator. There was no stratification in the sample except on the usage: residential or commerical. An average return of 15 to 20% was experienced during the test survey. A large portion of the test questionnaires (about 25 to 50 percent depending upon the category of the building) were returned by the post office, suggesting an inaccuracy in the address listings despite the fact that the list was the most accurate available. The test questionnaires which were returned were analyzed and it became apparent that many of the questions were ambiguous. The test questionnaire had too many queries, was too vague as to what information was desired and was too long.

The experience gained from the test survey was used to design the final questionnaire and establish the procedure of the survey. From the city records a more detailed listing of buildings was obtained. A new questionnaire (see appendix A) was then prepared, with the language altered, and the number of questions reduced. A modified sampling procedure was introduced based upon the recognition of the fact that within the basic categories of residential and commercial buildings, were 45 different but significant sub-categories of buildings usages, with from 10 to 6,000 properties in each sub-category. It was decided to stratify the samples using these individual types of building sub-categories.

The sampling procedure began by sending 200 questionnaires to each sub-category if it contained more than 200 entries. If there were fewer than 200 entries in a sub-category, questionnaires were sent to the entire population. Where ever applicable, a figure of either ten percent of the total population or 20 replies was to be the target figure. Because of the rate of unopened returns, in some cases it became necessary to send out from 50 to 200 additional questionnaires.

Once all the data had been received, coded, and analyzed (see IV) several points became apparent:

1. Some of the smaller sub-categories could be merged together due to their high degree of similarity.
2. The variance on all statistical parameters of many sub-categories was high.
3. Some data points were highly suspected of being classified incorrectly on the city lists.
4. In some cases, more data points would be necessary to arrive at any reasonable conclusions.

Observation 1 was handled simply by combining several small (under 20) residential sub-categories into one conglomerate residential sub-category. The other three problems, however, were interrelated and quite serious. If some of the addresses provided by the city listings were classified incorrectly, the stratified sub-categories could be non-homogeneous in composition. This possible inclusion of different buildings in the same group was considered, at least partly, as the cause of the high variance experienced.

One of the first steps taken to investigate the high variances was to further stratify the data. The underlying thought here was the possibility that the data was indicating a true state; that a lot of variation inherent in the sample was due to too broad a stratification procedure. The buildings within a particular sub-category were further separated by the method of collection of their solid wastes: city, private collection and self. This changed the variances in the quanity and cost questions. A large amount of variance had been inherent previously in the cost parameters because city collection is free, paid though taxes, and private is not. This type of variation had also occured in the quanity variables because city collection has a fixed limit on poundage (either 500 pounds of trash, and 50 pounds of garbage or 15 cubic feet), while private collectors do not. The next step was to separate buildings according to their sizes with a separation point of 10 stories. Again, intuitively, it seemed that a few large buildings in a group of smaller ones will effect the mean and variance excessively. Thus, the final data obtained in the survey was stratified into five distinct categories (see table 3).

This stratification resulted in reduced variances, but they still seemed high. Suspicion of incorrect city classification of some properties (observation 3), which may have been the cause of these high variances led back to the source of the orginal listings: the City of Philadelphia Finance Department Date Processing Center. Upon discussing the listing with the city representative, it was discovered that the portions of this particular listings were five years old. Nevertheless, this data was the most recent available. Owing to large scale urban renewal and new construction in the area, updating the list requires an inordinately large expendure of city funds.

The lack of an updated listing, however, did not effect the entire study area. The area where the majority of renewal had taken place was easily identifiable. A method was now needed to check data points from these areas. On the advice of Mr. George Gallup (private communication with Mr. George Gallup Jr. of the Gallup organization July 19, 1968.) It was decided to conduct a supplementary telephone survey. Therefore, a telephone interview was conducted with a total of 200 calls. These telephone interviews enabled collection of acceptable data for areas under question. They also provided a method to estimate, at least subjectively, the quality of a reply based on who was giving it. In addition to these in-depth interviews approximately 250 calls were made to check only the type of usage of a building in the renewal areas.

The telephone survey provided a great deal of information, both by adding data in all sub-categories (observation 4), and by confirming the proper sub-category of data points in question. In some cases, it was possible to change the sub-category of a building because, as a result of telephoning improper classification was discovered. This review materially improved the variances within the sub-categories. Table 3 shows the percentages of the total population of each major category (which contain the sub-categories) survey by either mailed questionnaire of telephone interview.

IV. DATA REDUCTION ANALYSIS

Each reply to the survey questionnaire or telephone interview was converted into standard units of measure (tons/yr., dollars/yr., etc.), and grouped together in the appropriate category defined by property size and collection mode as defined in Table 3. It was obvious that due to the nature of solid waste generation even with this detailed stratification, some inherent variation of data within like categories should be expected. To find a measure of this variation and detect large scale errors the mean, variance, standard deviation and coefficient of variation were computed for both quantity and cost variables in each category. In addition it was considered desirable to predict with known probablities (0.90), limits on the means of parameters computed from the raw data. The technique which was utilized to accomplish this, takes into account the variation in the survey and provides a range of values so that figures used in any planning study can be as conservative or non-conservative as desired and yet impart ninety percent confidence. Where applicable in the tables values are given for the mean, the high limit (probability that the mean value of the variable is less than the high limit= 0.90), and the low limit (probability that the mean value of the variable is greater than the low limit = 0.90) of each variable. The limits are calculated according to the procedure suggested by Bowker & Lieberman.(10)

V. RESULTS OF THE SURVEY

The survey provided detailed data on quantities collected and costs associated with their collection. These results are discussed below.

A) Physical Aspects - Table 4 summarizes the quantities of wastes collected according to the type of building usage and mode of collection. Since questions 2 and 3 of questionnaire are worded such that the answers to them provide information as to the volume of solid waste generated, this volume has been converted to weight by assuming an average unit weight of 15 lbs/cubic foot. This value was assumed as an average density for on-site stored waste in conjunction with the range of figures quoted in the literature.(11, 12) In terms of weight it is clear that the private collectors are the dominant force in the center city area. It is interesting to note that the survey estimate of the annual quantity collected by the city (60,100) is almost equal to the tonnage reported by the city as actually collected (55,300 tons). This may be taken as a positive check on the validity of the survey.

Table 5 indicates the relative importance of the waste generating units. In the case of organic material (answers to question 2 of questionnaire) residential units are the major waste generators on an aggregate basis owing to their large number. On a per building basis, however, restaurants and large office buildings, where restaurants or cafeterias are commonly located, predominate. Food operations represent a major activity in many buildings, including the large office buildings.

In regards to trash and inorganic material (answers to question 3 of questionnaire) industrial and manufacturing establishments generate the largest quantities. Many responses indicated that paper is a major waste of these units.

The results of question 6 indicated that local incineration is responsible for disposal of approximately 7 percent of the solid waste generated in the study area.

Incidental to achieving the major goal of the survey an interesting piece of information was obtained regarding the extent of the use of in-sink "garbage grinders". Table 6 shows the number of properties using these units. The high percentage of the use of these units, and the expectation of the increased installation in the future, imposes a sober question; how much longer the sewer lines in the city will operate before reaching their limits of solid carrying capacity?

B) Collection Costs - Tables 7 and 8 present both a summary of the collection costs for the study areas and data for individual property types. Values are given for the mean cost and high and low limits on the mean (as explained on page 7).

Observation of Table 8 shows that the properties used for stores and industrial work incur the largest portion of the collection costs. On a cost per ton basis, however, gas stations, parking lots, and large hotels are charged more.

In addition to private collection cost, Table 7 shows a city expenditure of $900,000 per year.

The cost incurred by the city was obtained from the city of Philadelphia, Department of Streets, Sanitation Division, through analyses of the department's annual report and personal interviews with department engineers. While the survey provided information on quantities of waste collection by the city, it did not yield the city's expenditure. The questionnaire intentionally ignored city collection costs because the feeling was that the average citizen or businessmen had no accurate knowledge of the amount of tax dollars used for collection.

Taking the final totals from Tables 4 and 7, an overall picture of the collection costs can be drawn. Using mean values the city spends $15.00 for each ton of solid waste collected (this does not include the cost of disposal).* Private collectors, on the whole, charge $7.00/ton collection charges excluding the cost of land fill.** It should be pointed out, however, that if private collectors cannot avail themselves of cheap land fill sites (less than $1.00/ton dumping costs), they will be forced to utilized city incinerators at a charge of $8.00/ton and the cost will be directly passed along to the waste generators. The city's own incineration cost per ton could not be established with accuracy. While on the surface the cost per ton of collection seems to be higher to the city than private collectors, it should be remembered that city collects from small waste generators while private collectors, in general, collect from large waste generators.

Table 8 reveals a very interesting fact about cost per ton of collection by private collectors. This table shows the wide range of costs per ton charged in the study area. This is the result of failure to regulate or standardize the rate schedules of private collectors. One such collector, in a telephone interview, reported that "Prices are set completely arbitrarily, with no two collectors charging the exact same rate for the same kind of building". This arbitrary rate structure gives rise to not only widely divergent cost but also encourages equally erratic service.

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* According to the City's Department of Streets, Sanitation Division, 1967 report, the average cost of city collection per ton on city wide basis was about $16.80.

** As it was mentioned previously the city collects some of the solid wastes in the study area through contracts with private collectors. The payments to these private collectors averaged $8.37 a ton in 1967.

C) Acceptance of present system - This some $2.5 million for collecting the solid waste generated in a small portion of the city is spent most reluctantly. Table 9 summarizes the survey results concerning this issue of satifaction with the present collection system. Those surveyed were asked to indicate whether or not they are dissatisfied with the present collection system by checking a list provided for them. It can be seen that the majority of users are dissatisfied. No claim is made that the results of this particular question constitutes any startling social commentary or represent a mandate for change in the present collection scheme. They only serve to point out that most of the people and businesses served by the present collection system "feel" that it is in many ways inadequate.

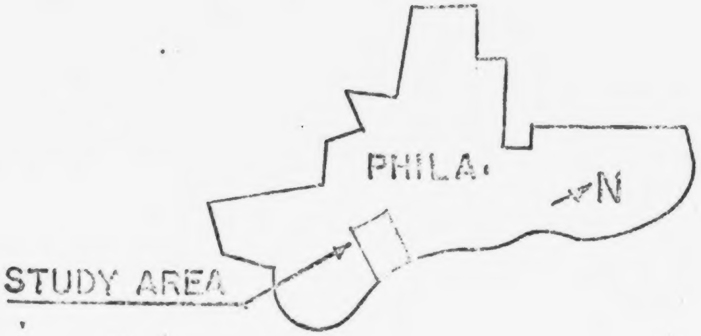
Another response of some interest was made to the question of the maximum rate the occupants were willing to pay for a better system of collection. Many residential owners were willing to pay significantly more than now but commerical building owners did not want to expend more. The results of this question, however, are of doubtful use since many people apparently were not aware of the present level of public expenses for collection through taxes. Some respondents also indicated that they felt they were being excessively charged at the present time and expressed disapproval of any action resulting in higher collection charges.

VI CONCLUSION

This study represents an effort to discover some salient elements of the solid waste collection process in the core of a major city. The identity of the waste producers, the quantities and types of wastes, the cost of collections, and the evaluation of the present system by those serviced were all explored. This type of information should prove valuable in planning and designing any removal system and in estimating its costs.

ACKNOWLEDGEMENT

This investigation was supported in whole by a Public Health Service Research Grant, Number UI 005431-02 from the Bureau of Solid Waste, Environmental Control Administration, United States Public Health Services.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STUDY AREA

TABLE 1

SOME INFORMATION ABOUT THE STUDY AREA (CENTER CITY PHILADELPHIA)

Area:		
City of Philadelphia	130.0	square miles
The Study Area	3.22	square miles
As a Percentage of the City	2.5	percent
Total Length of Streets	72.0	miles
Average Length of the Study Area	2.3	miles
Average Width of the Study Area	1.4	miles
Population (1960):		
City of Philadelphia	2,055,200	
Study Area	47,270	
As a Percentage of the City	2.3%	

* This is the permanent population and does not include the transient day workers.

TABLE 2

PROPERTY TYPES IN STUDY AREA

Type of Property	Commercial (C) or Residential (R)	Number of Units	Per Cent of Total
Amusements (theaters, movies, clubs, standia)	C	140	0.9
Apartment Houses (4 units or less)	R	140	0.9
Apartment Houses (more than 5 units)	C	286	1.8
Bank and Office Building (ground floor occupied by the bank proper, other floors used for general office space)	C	39	0.3
Financial Building (exclusively used by banks and brokerage houses.	C	23	0.2
Garages (multi-automobile, public and private)	C	326	2.2
Gas Stations	C	52	0.3
Home Converted to Apartments	R	925	6.1
Homes	R	6,762	44.9
Home with Office or Store	R	1,855	12.3
Hotels	C	39	0.3
Industrial (shops, mills, foundaries, etc.)	C	521	3.5
Loft or Light Manufacturing	C	513	3.4
Miscellaneous	C	248	1.7
Office Building	C	220	1.5
Parking Lots	C	375	2.5
Private Garages (limited space garages used residentially.)	R	12	0.1
Restaurants	C	99	0.7
Schools	C	24	0.2
Small Hotels or Rooming Houses	R	150	1.0
Store (or Office) and Apartment	R	680	4.5
Stores	C	1,130	7.5
Stores and Offices	C	480	3.2
TOTAL		15,039	100.0

TABLE 3

Categories of Properties Considered and Percentage Sampled

(x indicates the relevance)

Type	Property Usage		Mode of Collection			Size of Property		% of Sub-category Population surveyed
	Comm.	Res.	Priv.	City	Self	Less Than 10	More Than 10	
1	x		x			x		7.8 (219/2,818)**
2	x		x				x	31.3 (41/231)
3	x			x		x		9.8 (154/1,566)
4		x	x			x		7.7 (18/234)
5		x		x		x		1.7 (171/10,290)*

* The low percentage sampled was due to similarity of properties and very low variance in data taken.

** Figures in parenthesis indicate the number of samples over the total population.

TABLE 4

Overall Quantities of Solid Wastes Collected[d]
in 1000 tons/yr. (survey results)
(1968)

	Lower Limit[a]	Mean	Higher Limit[a]
City Collection			
Commercial	8.8	11.8	14.8
Residential	41.7	48.3	55.0
Sub Total I.	50.5	60.1	69.8
Private Collection			
Commercial	120.1[e]	186.0[e]	251.9[e]
Residential	4.2	7.0	9.8
Sub Total II.	124.3	193.0	261.7
Totals[b]	175.0[c]	253.0[c]	331.0[c]

a. For definition see page 7
b. Totals do not include 4,150 tons of bulky refuse (furniture, large pieces of scrap metal, etc.) collected in 1968
c. These figures are rounded to the nearest thousand.
d. Fragmentary returns stating that solid waste was self-collected were received. Projected totals were only approximately 5000 tons/yr. and are not included in this table.
e. Categories 1 and 2 (Table 3) are shown together under commerical usage with private collection.

Table 5
Quantities of Waste by Types of Properties
(1968)

Type of Property	Usage	No. of Units	No. of Replies (% of Replies)	Mode of Collection	Size, Stories	Quantity of Waste Ton/Yr./Unit *					
						Organic Mat'l Mean ***	Inor-ganic Mat'l ****	Bulky Mat'l	Total Waste **		
									Low *** Limit	Mean	High *** Limit
Type 1:											
Stores	C	750	27 (3.6%)	Private	< 10	3.0	32.2	1.1	29	36	43
Stores & Offices	C	305	24 (7.9%)	Private	< 10	3.7	32.0	1.0	28	35	44
Apartment	C	75	6 (33.3%)	Private		4.0	5.9	0.0	6	10	14
Office Buildings	C	95	4 (19.0%)	Private	< 10	2.6	82.9	0.2	66	86	106
Bank & Office	C	18	22 (6.9%)	Private	< 10	0.2	37.3	0.3	16	37	58
Hotels	C	21	4 (19.0%)	Private	< 10	26.0	15.1	5.0	25	46	67
Light Mfg.	C	321	22 (6.9%)	Private	< 10	1.4	103.0	0.6	73	104	135
Financial	C	23	8 (34.8%)	Private	< 10	2.4	43.4	0.0	21	46	71
Restaurant	C	99	16 (16.2%)	Private	< 10	33.8	62.0	0.0	59	96	123
Amuse-ment	C	85	12 (14.1%)	Private	< 10	10.7	23.0	0.1	25	34	43
Industrial	C	369	24 (6.5%)	Private	< 10	2.9	84.9	1.3	49	88	127

Continuation of Table 5

Type of Property	Usage	No.of Units	No.of Replies (% of Replies)	Mode of Collection	Size Stories	Quantity of Waste Ton/Yr./Unit *					
						Organic Mat'l Mean ***	Inor-ganic Mat'l ****	Bulky Mat'l	Total Waste **		
									Low *** Limit	Mean	High *** Limit
ype 2:											
Stores & Offices	C	25	9 (36%)	Private	> 10	23.4	177.3	3.3	123	201	279
Apart-ments	C	36	10 (27.8%)	Private	> 10	27.4	199.6	1.0	169	246	323
Office Buildings	C	40	10 (25%)	Private	> 10	110.8	218.3	2.6	185	330	475
Bank & Office	C	12	4 (33.3%)	Private	> 10	7.8	201.5	0.0	167	209	251
Hotels	C	18	8 (44.4%)	Private	> 10	77.2	174.3	0.8	116	267	418
Industrial	C	12	4 (33.3%)	Private	> 10	13.4	388.4	11.8	184	394	604
ype 3											
Stores	C	380	19 (5.0%)	City	< 10	0.5	6.6	0.03	6	7	8
Stores & Office	C	150	14 (9.3%)	City	< 10	0.8	7.1	0.4	6	8	10
Apart-ments	C	175	28 (16.0%)	City	< 10	2.4	4.7	0.7	.7	8	9
Office Building	C	85	22 (25.9%)	City	< 10	0.7	6.4	0.2	6	7	8
Bank & Offices	C	9	3 (33.3%)	City	< 10	0.0	3.5	0.0	3	4	5
Light Mfg.	C	192	14 (7.3%)	City	< 10	1.0	12.3	0.4	8	13	18
Amusement	C	55	14 (25.5%)	City	< 10	1.7	11.2	0.1	10	13	16

Continuation of Table 5

Type of Property	Usage	No. of Units	No. of Replies (% of Replies)	Mode of Collection	Size Stories	Quantity of Waste Ton/Yr./Unit *					
						Organic Mat'l Mean***	Inor-ganic Mat'l****	Bulky Mat'l	Total Waste **		
									Low*** Limit	Mean	High *** Limit
Industrial	C	140	10 (7.1%)	City	< 10	2.2	5.1	0.1	4	7	10
Parking Lot	C	170	7 (4.1%)	City	< 10	1.3	1.2	0.0	3	3	3
Misc.	C	124	15 (12.1%)	City	< 10	1.5	5.3	0.0	5	7	9
Public Garage	C	86	8 (9.3%)	City	< 10	1.3	2.6	0.0	3	4	5
Type 4;											
Small Apts.	R	9	4 (44.4%)	Private	< 10	2.9	0.9	0.0	3	4	5
Rooming House	R	85	10 (11.8%)	Private	< 10	7.8	12.6	0.6	14	21	28
Store & Apt.	R	140	4 (2.9%)	Private	< 10	6.5	30.3	0.3	21	37	53
Type 5											
Homes & Garage	R	46	7 (15.2%)	City	< 10	4.0	1.5	0.0	2	5	8
Semi-row Home	R	67	8 (11.9%)	City	< 10	1.8	4.3	0.1	6	7	8
Row Home	R	6,649	38 (0.6%)	City	< 10	0.9	3.1	0.0	3	4	5
Row with Office	R	1,855	13 (0.70%)	City	< 10	1.6	3.6	0.1	5	6	7
Row Apts.	R	925	27 (2.9%)	City	< 10	1.6	4.6	0.0	5	6	7

Continuation of Table 5

Type of Property	Usage	No. of Units	No. of Replies (% of Replies)	Mode of Collection	Size Stories	Quantity of Waste Ton/Yr./Unit *					
						Organic Mat'l Mean ***	Inor-ganic Mat'l	Bulky Mat'l	Total Waste **		
									Low *** Limit	Mean	High *** Limit
Apart-ments	R	131	46 (35.1%)	City	< 10	2.0	4.6	0.0	7	7	7
Store & Apts.	R	540	21 (3.9%)	City	< 10	1.4	3.2	0.0	5	5	5
Rooming House	R	65	8 (12.3%)	City	< 10	2.7	4.5	0.0	5	7	9

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* For definition of organic and inorganic material as applied to survey. See questions 2 and 3 in questionnaire, Appendix A.

** Values of mean total waste may not be equal to the sum of organic and inorganic material due to rounding errors.

*** Variances on quanity are not shown explicityly but are contained in the high and low limit values of the mean.
See page 7 for description of these limits.

Continuation of

TABLE 6

INCIDENCE OF IN-SINK GRINDERS BY SELECTED TYPE OF BUILDING

Building Type	Commercial (C) or Residential (R)	Number of Units	Number of Units Using Grinders	Percent Using Grinders
Hotels	C	39	0	0
Industrial	C	521	28	5
Loft or Light Mfg.	C	513	0	0
Miscellaneous Commercial	C	248	82	33
Office Building	C	220	21	10
Parking Lots	C	375	0	0
Restaurants	C	99	6	6
Stores	C	1,130	56	5
Stores and Apartments	R	680	180	26
Stores and Offices	C	480	36	7
TOTAL		15,039	4,128	27

TABLE 6

INCIDENCE OF IN-SINK GRINDERS BY SELECTED TYPE OF BUILDING

Building Type	Commercial (C) or Residential (R)	Number of Units	Number of Units Using Grinders	Percent Using Grinders
Amusement	C	140	4	7
Apartments	C	286	103	36
Apartments	R	131	60	46
Financial	C	23	0	0
Bank & Office Bldg.	C	39	0	0
Garages	C	326	0	0
Garages	R	42	0	0
Gas Stations	C	52	0	0
Homes Detached	R	46	6	14
Homes Semi-detached	R	67	34	50
Row Home	R	6,649	2,793	42
Row with Office & Store	R	1,855	427	23
Row connected to Apartments	R	925	342	37
Hotels (small)	R	150	16	10

TABLE 7

Summary of Collection Costs for Study Area in Million Dollars (1968)

	Low* Limit of Mean	Mean	High* Limit on Mean
City Collection			
Commercial	———	———	———
Residential	———	———	———
Sub Total I **	0.90	0.90	0.90
Private Collection			
Commercial	0.85	1.22	1.81
Residential	0.06	0.08	0.10
Sub Total II	0.91	1.30	1.91
Totals ***	1.80	2.20	2.80

* See page 7 for definition of low and high limits on mean.

** City cost data based on City of Philadelphia, Department of Streets, Sanitation Division, Annual Report of 1967.

*** These totals do not include disposal costs. Disposal costs were subtracted on the basis of city figures and interviews with private collectors in the study area.

TABLE 8 - Private Cost Variables For Commerical Properties
(1968)

Building Type	No. of Units	Size	Cost Per Building Per year from survey			Total Cost per yr.			$/Ton**		
			Low limit on mean	Mean	High limit on mean	Low * Limit on mean	Mean*	High* Limit on mean	Low Limit on mean	Mean	High Limit on mean
Stores	750	<10	287.00	356.00	425.00	215602	267333	319063	9.66	11.87	14.09
Stores & offices	305	<10	201.00	242.00	282.00	61475	73886	86297	7.75	11.04	14.33
"	25	>10	666.00	900.00	1134.00	16648	22500	28351	5.09	7.21	9.34
Apt. Houses	75	<10	83.00	184.00	285.00	6211	13800	21388	12.96	26.49	40.03
"	36	>10	1147.00	1704.00	2260.00	41299	61344	81388	6.22	8.01	9.80
Office Bldg.	95	<10	540.00	688.00	836.00	51346	65419	79491	9.13	11.53	13.93
"	40	>10	1086.00	1689.00	2292.00	43447	67566	91685	5.33	7.99	10.64
Bank & Offices	18	<10	133.00	271.00	410.00	2401	4893	7384	6.98	9.10	11.22
"	12	>10	906.00	1575.00	2243.00	10879	18900	26920	4.34	7.43	10.52
Hotels	18	>10	2078	5746	9414	37406	103437	169467	10.08	25.23	40.38
"	21	<10	118	475	831	2487	9975	17462	7.66	19.55	31.44
Light Mfg.	321	<10	465	574	684	149264	184560	219856	7.17	9.16	11.16
Financial Bldg.	23	<10	126	171	217	2906	3947	4988	3.41	6.56	9.72
Restaurants	99	<10	487	612	736	48288	60606	72924	7.07	9.06	11.04
Amusements	85	<10	305	388	471	25963	33015	40067	11.40	17.56	23.72

Continuation of Table 8

Building Type	No. of Units	Size	Cost Per Building Per year from survey			Total Cost per yr.			$/Ton**		
			Low limit on mean	Mean	High limit on mean	Low * Limit on mean	Mean*	High* Limit on mean	Low Limit on mean	Mean	High Limit on mean
Industrial	369	<10	408	644	880	150705	237728	324751	12.16	15.49	18.83
"	12	>10	1009	2441	3872	12111	29292	46472	4.41	7.99	11.57
Public Garage	240	<10	201	312	421	48411	74777	101142	11.30	13.59	15.88
Parking lot	205	<10	134	179	223	27574	36684	45795	17.12	35.20	53.28
Gas Stations	52	<10	117	299	481	6084	15548	25011	2.91	32.79	62.66
Schools	24	<10	26	180	333	633	4320	8006	0.21	4.87	9.53
Misc.	124	<10	264	338	411	32820	41950	51079	15.72	22.76	29.80

* If these columns are summed, 15% must be subtracted for cost of disposal to private collectors (New Jersey land fill) to obtain the figures in Table 6.

** The dollar per ton ratios were constructed as follows: In each sub-category, a $/ton ratio was computed from each reply to the survey. These separate $/ton ratios were summed and divided by the total number of replies to obtain a mean $/ton ratio for the type of building in that sub-category.

TABLE 9

OBJECTIONS TO PRESENT COLLECTION SYSTEM BY WASTERS

	Percent Objecting to the Following Specific Characteristics						
Building Type	Trash Cans	Smell	Inconvenience	Bugs	None	More Than One	No Response To This Question
Amusement	28.6	0	0	7.1	7.1	35.7	21.5
Apartment Houses (4 units)	0	2.2	0	0	4.4	76.1	17.3
Apartment Houses (5 units or more)	10.7	0	0	0	3.6	75.0	10.7
Bank and Office Buildings	0	0	0	0	66.7	0	33.3
Detached Residential	0	0	0	0	14.3	57.1	28.6
Garages	0	0	0	0	25.0	25.0	50.0
Industrial	10.0	0	0	0	0	50.0	40.0
Loft or Light Mfg.	14.3	0	0	0	7.1	28.6	50.0
Misc. Commercial	13.3	6.7	0	0	13.3	26.7	40.0
Office Buildings	13.6	0	0	0	9.1	59.1	18.2
Parking Lots	0	0	0	0	28.6	42.9	28.5

Continuation of

TABLE 9

OBJECTIONS TO PRESENT COLLECTION SYSTEM BY WASTERS

Building Type	Percent Objecting to the Following Specific Characteristics						
	1. Only Trash Cans	2. Only Smell	3. Only Inconvenience	4. Only Bugs	5. None	6. More Than One of first four	7. No Response To This Question
Private Garages	0	0	0	0	0	100.0	0.0
Row converted to Apartments	18.5	0	0	0	14.8	63.0	3.7
Row Residential	5.3	5.3	0	0	21.1	55.3	13.0
Row with Office or Store	7.7	0	0	7.7	15.4	61.5	7.7
Semi-detached Residential	0	0	0	0	0	100.0	0.0
Small Hotels or Rooming Houses	0	0	0	0	0	62.5	37.5
Store and Apartment	14.3	0	0	4.8	4.8	61.9	14.2
Stores	15.8	0	0	0	0	68.4	15.8
Stores and Offices	35.7	0	0	0	14.3	28.6	21.4

APPENDIX A

Questionnaire

(1) Who removes your refuse (all disposable matter) from the premises?
☐ City ☐ Self ☐ Private Collector

(2) What is the amount of garbage such as food, plants, etc., collected in an average week?

Container	Number	Size (Approx.)
Cans		
Bags		
Other		

(3) What is the amount of other solid waste such as paper, cans, bottles, and miscellaneous industrial waste that is collected in an average week?

Container	Number	Size (Approx.)
Cans		
Bags		
Other		

(4) If you employ a private collector, what is the average cost?

$ Per Week	$ Per Month	$ Per Year
________	________	________

(5) If you remove your own refuse, how much does it cost you?

$ Per Week	$ Per Month	$ Per Year
________	________	________

(6) How much of your total refuse (all disposable matter) do you incinerate on the premises?

☐ None ☐ 1/4 ☐ 1/2 ☐ 3/4 ☐ All ☐ Other (please specify)

(7) Do you dispose of large bulky material, such as furniture, scrap metal, Etc.? If so, how much?

Per Week	Per Month	Per Year
________	________	________

(8) Do you use a sink disposal for food waste?
☐ Yes ☐ No

(9) What are your major objections to the present system for collecting refuse?

☐ Handling trash cans
☐ Smell
☐ Inconvenience
☐ Rats, Flies, Insects
☐ Other (Please specify)

(10) What is the maximum amount you would pay for an automatic pipe system for collecting refuse? A system which would eliminate the objections listed in question 9.

Please circle. ($ Per Month)

(0-5 $) (5-10 $) (10-15 $) (over 15 $)

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Appendix IV

Cost-Benefit Analysis of Pneumo-Slurry Systems

Acknowledgment: This material has been excerpted from a paper which was published by Iraj Zandi and John A. Hayden as chapter 16 of a Pergamon Press book entitled: "Advances in Solid Liquid Flow in Pipes and Its Application". The original paper was published under the title of "A Pneumo-slurry System of Collecting and Removing Solid Wastes".

Appendix IV

Cost-Benefit Analysis of Pneumo-Slurry Systems

Note: Whether solid waste pipelines will be considered as a future means of collecting and removing domestic, commercial, and some industrial waste depends largely on its cost as compared with the truck-collection system. To make a realistic comparison, the center city of Philadelphia was chosen as the study area. In order to compare the cost of truck collection with the cost of the proposed pipe systems several steps were taken. First, a compilation was made of the cost of the current collection and removal of waste generated in the study area. Then an estimate of the costs of the present system was attempted. Having then looked at the relevant costs of the present system for 1968, a projection of these costs for the future was made (see Section a). Secondly, a system of pipeline transport for the study area was designed and its cost was estimated (see Section b). Finally, a benefit-cost analysis was made using the costs of the present system as a measure of the benefits of the proposed pipeline system. An appropriate discount rate (6 percent) was selected to convert all these benefits.

Cost-Benefit Analysis of Pneumo-Slurry Systems

Table 1 indicates some of the characteristics of the study area and provides useful information. This portion of Philadelphia contains the central business district with much commercial property. There is also a great deal of rental housing, especially in the form of small apartment units.

TABLE 1. SOME INFORMATION ABOUT THE STUDY AREA[a]
(Center City Philadelphia)

	Area in[b] sq. miles	Population in residence (1968)	Solid waste collected[c, d] by city (1968) in tons	Municipal expenditures[c, d] for collection (1968)
City of Philadelphia	130.0	2,073,000	900,000	$15,250,000
The Study Area	3.22 av. length = 2.3 av. width = 1.4	48,000	55,300	$900,000
The Study Area as percentage of the city	2.5	2.3	6.2	5.9

[a] Real properties existing in Study Area: Residential (under 10 stories) 10,524,
Commercial (under 10 stories) 4,372,
Commercial (over 10 stories) 143 each.

[b] There are 72 miles of streets in the Study Area.

[c] These figures do not include private collection figures.

[d] These figures obtained through the City of Philadelphia, Sanitation Department.

(a) Benefit (cost of present system)

Since the aggregate benefits of the new pipe system represents the projected costs of the present system, an estimate of projected costs of the present system over the next 50 years was made. This includes the direct collection cost and the spillover or indirect cost of the present arrangements. Tables 2 and 3 indicate the cost of the present system over the next 50 years converted to 1968 basis.

Table 2. Quantities and Costs of the Truck Collection System for Study Area Determined by Survey

	1968		Design period (50 years)	
	Quantities in 1000 tons	Cost in millions of $	Quantities estimated in the 50th year in 1000 tons	Summation of yearly costs of 50 years discounted to 1968 value
	Mean	Mean	Mean	Mean
A. City Collection				
1. Commercial	11.84	---	31.9	---
2. Residential	48.30	---	130.0	---
Sub-total I	60.14	0.90[a]	161.9	27.6
B. Private Collection				
1. Commercial	186.0	1.22	501.0	37.37
2. Residential	7.0	1.08	18.9	2.55
Sub-total II	193.0	1.30	519.9	39.92
Totals[b,c]	253.0	2.20	681.0	67.50

[a] City cost data is based on the City of Philadelphia, Senitation Department.

[b] Totals do not include bulky material (furniture, large pieces of scrap metal, etc.) 4150 tons of bulky material were collected in 1968. The estimate for the 50th year is 11,200 tons.

[c] The cost figures do not include disposal costs. Disposal costs were subtracted on the basis of City figures and interviews with private collectors in the study area.

TABLE 3. INDIRECT COST OF PRESENT SYSTEM, MILLIONS OF DOLLARS OVER NEXT 50 YEARS

Air pollution effects[a]	
On residents	2.6
On workers of business district	41.2
Traffic accidents[b]	0.2
Rat control	0.3
Saving on receptacle	1.7
Convenience[c]	?
Health, other than air pollution[c]	?
Alleviation of traffic congestion due to collection trucks[c]	?
Slum cleaning[c]	?
Fire hazard reduction[c]	?

[a] Methods of ref. 11 were used for estimating these items.

[b] Only extra insurance was considered.

[c] No monetary value can be assigned to these.

Direct benefit (cost of present system) was estimated from data supplied by the city and those resulting from the survey (see Appendix III).

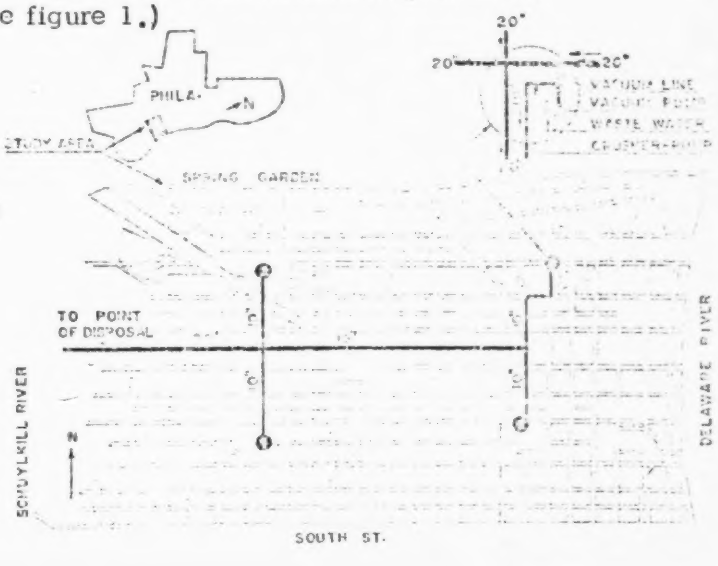
The estimate of the indirect cost of the present system involves a rather complicated procedure and will be described elsewhere. A summary is shown in Table 3. The basis for these estimates are the Aerojet(1) study of 1965 and consultations with a number of experts. Since some controversy may be provoked by these items it is only mentioned for the sake of completeness. The process of comparing the present truck collection system with the pipeline in this study will only take into account the direct costs.

(b) Cost of Pipeline System .

In order to estimate the cost of pipeline systems, a number of alternative pipeline networks were examined.

The final scheme which was adopted is a combination of pneumatic systems and slurry pipelines. (See figure 1.)

Figure 1. Study Area, Pneumo-Slurry System (Pneumatic pipelines are not shown. There are 20" vacuum lines in all streets.



The pneumatic system was designed according to the procedures suggested in the report elsewhere. It is important to note that the technology needed for the proposed system is already available. A 6 percent concentration was selected because at the time of study reliable data for 6 percent concentration was available.

Tables 4,5,6 and 7 show the basic calculations involved in the design of the new system, and prices used for cost estimation. The unit prices selected are all conservative, checked with a number of consulting firms and are about the same as those used by the City of Philadelphia's Water Department. The tables are self explanatory and clearly indicate that all costs including installations, operation, and maintenance are considered.

TABLE 4. COST OF PIPELINE INSTALLATION IN THE STUDY AREA

Mode of transport	Pipe diam. in inches	Unit price[c] of pipe (sched. 40) per ft in $	Unit price[c] of construction per ft in $	Total price per ft in $	Total price per mile in $	Length in miles	Total cost per pipe diameter	Additional cost to disposal points		
								0 miles	20 miles	50 miles
Slurry[a]	10[d]	10.00	12.38	22.38	118,850	1.36	209,175[d]			
Slurry[a]	16	20.16	12.38	32.54	172,075	1.00	172,075			
Pneumatic[b]	20[d]	28.08	12.38	40.46	213,892	98.70[e]	23,709,000[d]			
Slurry[a]	22	32.40	12.38	44.78	236,700	0.50	118,350			
Pneumatic[b]	24	36.70	12.38	49.08	259,610	4.00	1,038,450			
Total cost to boundary of study area							25,247,000			
Total cost to points of disposal								25,247,000	29,981,000	37,082,000

[a] Slurry pipelines were designed based on information obtained in present study. The estimates are quite conservative.
[b] The pneumatic system was designed according to ref. 11.
[c] Prices obtained through the consulting firms.
[d] In 5.2 miles of the system because of the necessity for hand excavation the unit cost estimate was tripled.
[e] 27.1 miles of this figure are house connections.

TABLE 5.[*] COST OF CRUSHERS, PUMPS, BLOWER UNITS, FILTERS (AIR) AND DISCHARGE VALVES (VACUUM SEALS)
(For 890,000 tons/year solid waste generated at the end of 50 years)

Item	Number required	Cost per unit in dollars	Total cost in dollars
Crusher pumps	62†	35,000[a]	2,170,000
Vacuum blowers	24†	26,000[b]	625,000
Filters (air)	24†	12,000	288,000
Slurry pumps for: 20 miles	60†	2,200[c]	132,000
50 miles	120†	2,220[c]	264,000
Discharge valves (vacuum seals and air intake assembly)	15,000	4,000[d]	60,000,000

[*] These prices are 1968 prices and do not take into account the reductions in price due to the advancements in technology and mass production.

† 12 crushers, 8 blowers, 8 filters, 10 pumps (for 20 miles) and 20 pumps (for 50 miles) are standby units.

[a] This is the price of a Wascon Pulper ($27,000) and Dorr-Oliver Gorator ($3,500) in series, plus $4,500 for mortage. Prices were obtained from these company's representatives.

[b] This is the price of a Roots-RVS, rotary, positive wet vacuum blower, 18000 cfm in line producing 10 in. Hg vacuum. Price was obtained from Roots Connersville Company.

[c] These are prices of Wemco, Model C, 1200 gal/min at 80 ft. Prices obtained from A, B, & G Co., Philadelphia, Pa.

[d] The seals were assumed to be similar to the Swedish design. Prices were estimated through consultation with the manufacturing industry.

TABLE 6. OPERATING COST—ELECTRICITY
(For 331,000 ton/year solid waste at 1968 level—20 hours a day operation)

To boundary of study area				Additional HP required for removal to point disposal			Total HP required to point of disposal		
Unit	Number of units	HP per unit	Total HP	0 miles	20 miles	50 miles	0 miles	20 miles	50 miles
Vacuum blower	8	500	4000						
Crusher and pump	20	150	3000						
Slurry pump				0	1200	3000			
Total HP							7,000	8,200	10,000
Equivalent kWh/year							37,400,000	43,300,000	53,500,000
Unit cost $/kWh							1.2*	1.2*	1.2*
Total cost in dollars							450,000	526,000	645,000

* The cost per kilowatt hours obtained from the Philadelphia Electric Company. This is mass use rate.

TABLE 7. BASIS FOR COST STUDY[*]
(Installation, operation and maintenance)

Item	Life expectancy in years	1968 price in millions of $	50 years price in millions of $		
			point of disposal		
			0 miles	20 miles	50 miles
Installation					
1. Pipe removal to:					
(a) boundary of study area	50	25.20	25.20		
(b) 20 miles	50	30.00		30.00	
(c) 50 miles	50	37.10			37.10
2. Air seals and house fittings:					
(a) unmoving parts	50	37.00	37.00	37.00	37.00
(b) moving parts	25	16.00	24.00	24.40	24.40
(c) delicate parts	10	2.15	6.62	6.62	6.62
3. Crusher and pump:					
(a) unmoving parts	25	1.63	1.18	1.18	1.18
(b) moving parts	10	1.00	0.90	0.90	0.90
4. Vacuum blowers and filters	10	0.91	0.97	0.97	0.97
5. Supplementary[a] collection of bulky material		0.10	3.00	3.00	3.00
6. Pumps (slurry) to:					
(a) 20 miles	10	0.13		0.13	
(b) 50 miles	10	0.26			0.26
7. Pump houses[b]			1.00	1.25	1.75
Operation (annual)			10.17	12.10	14.20
Maintenance					
1. 0.5% for pipes and unmovable parts of seal			5.14	5.50	6.07
2. 3.5% for blowers, crushers and movable parts of seals			13.34	13.34	13.34
Total			128.9	136.4	146.8

[*] These costs do not take into account the reduction in prices due to advances in technology and mass production.

[a] Supplementary collection cost taken to be $20/ton.

[b] Pump houses were estimated according to the procedures of the City of Philadelphia Water Department.

(c) Comparison

Table 8 compares the costs-benefits of the pipeline system. Direct costs of the present system were assumed to be the benefits of the pipeline system. For the purpose of comparison three alternate points of disposal were selected (zero, 20 and 50 miles). Comparison was made for the design period of 50 years.

According to these estimates, the City of Philadelphia will expend, in direct costs, some 153.2 million dollars using mean values, to collect and remove to a distance of 50 miles the solid waste which will be generated in the Center City area, for the next 50 years. During this same period of 50 years the solid waste pipeline costs are estimated to be 146.8 million dollars. These figures show that pipeline transport of solid waste, economically speaking, is at least in the same competitive neighborhood as the present truck collection, even while disregarding the secondary benefits of the pipeline system.

TABLE 8. COSTS AND BENEFITS COMPARISON
(Pipeline system *vs.* truck collection)[a]

Design period	With present technological capabilities in millions of dollars (these systems can be constructed today)						With moderate advances[b] in crushing and pumping techniques and cost reduction of discharge valves due to mass production					
Distance to disposal site	0 miles		20[c,d] miles		50[c,d] miles		0 miles		20[c,d] miles		50[c,d] miles	
Mode of collection	Truck collection	Pipeline[e] collection	Truck collection	Pipeline[e] collection	Truck collection	Pipeline[e] collection	Truck collection	Pipeline[e] collection	Truck collection	Pipeline[e] collection	Truck collection	Pipeline[e] collection
50 years study period using: 1. Mean of present costs	67.50	128.9	100.6	136.4	153.2	146.8	67.50	105.6	100.6	112.7	153.2	122.6

[a] The indirect benefits of pipeline systems are not included in this comparison.

[b] A 25 percent decrease in the costs of blowers, crusher-pumps and discharge valves (vacuum seals) is assumed.

[c] Cost of truck transport is assumed to be 5¢/ton/mile in accordance with ref. 1.

[d] An annual increase of 2.0 percent in quantity of solid waste is assumed.

[e] These figures are the summation figures shown in the last row of Table 7. They include the collection of bulky material which is $3,000,000 over the next 50 years at the 1968 cost (estimated that it will cost $20/ton to remove the bulky materials).

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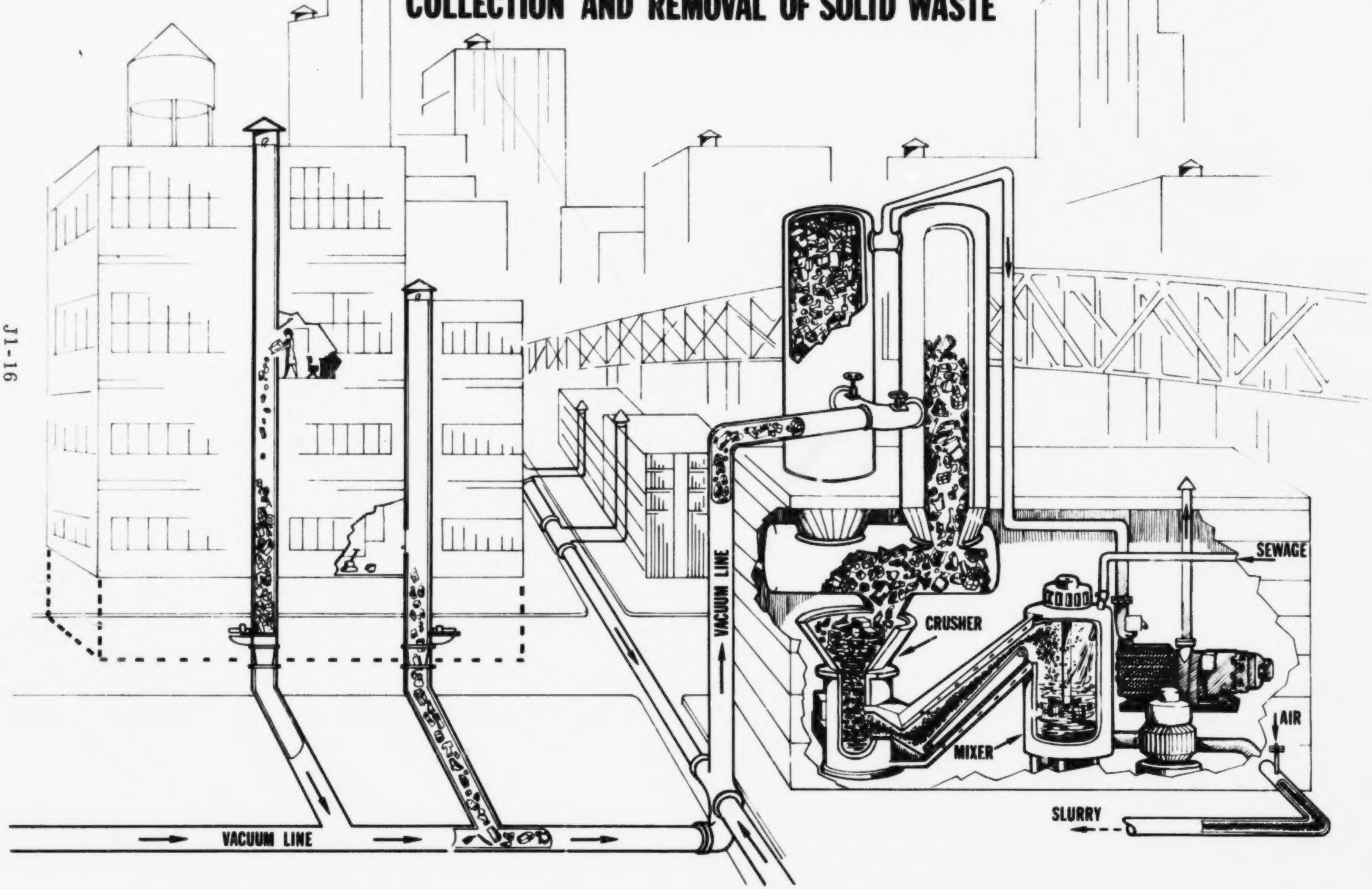
PNEUMO-SLURRY SYSTEM
OF
COLLECTION AND REMOVAL OF SOLID WASTE


VACUUM LINE
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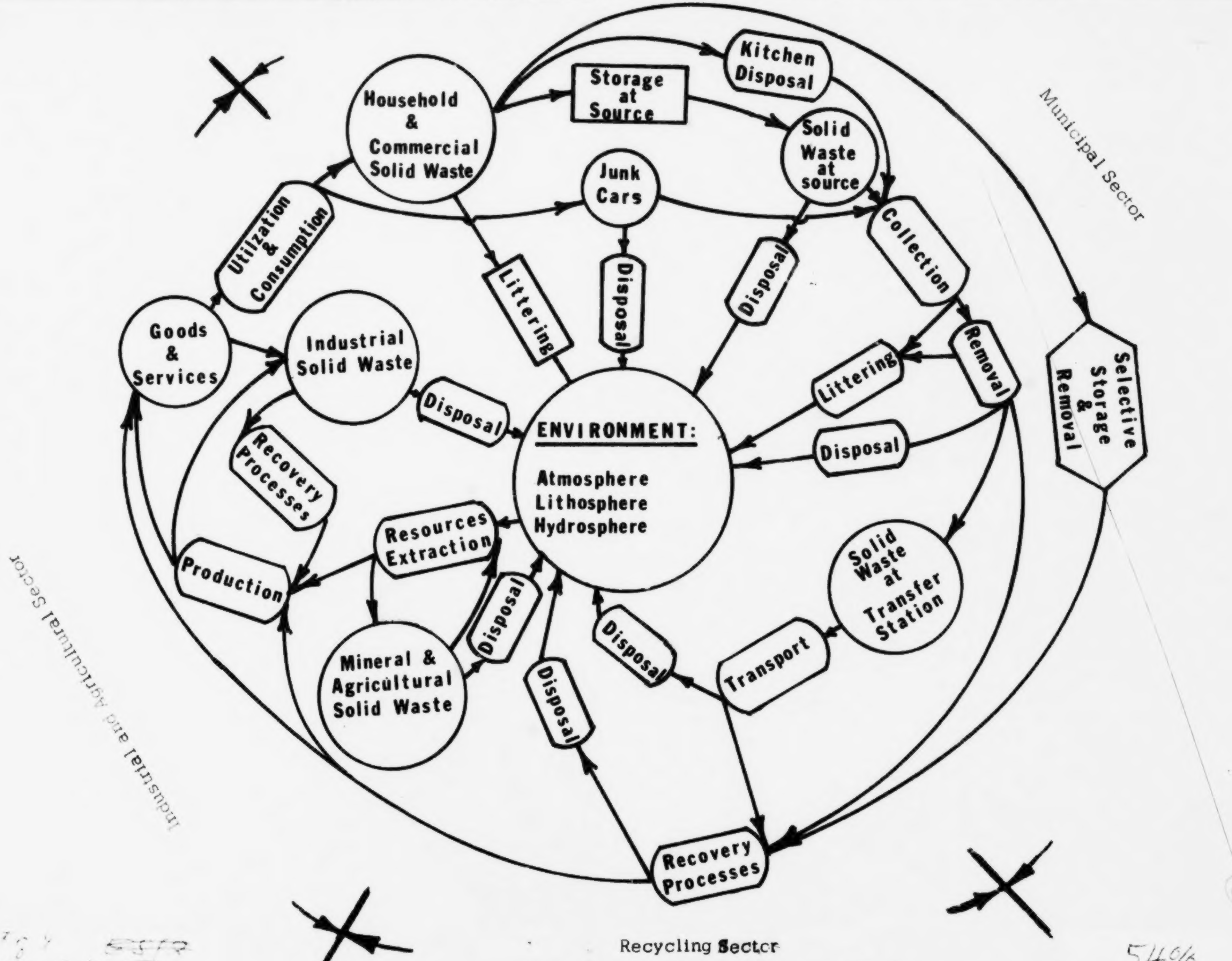
Municipal Sector
Industrial and Agricultural Sector
Recycling Sector
Household & Commercial Solid Waste
Storage at Source
Kitchen Disposal
Solid Waste at source
Junk Cars
Collection
Removal
Selective Storage & Removal
Utilization & Consumption
Goods & Services
Industrial Solid Waste
Littering
Disposal
Disposal
Littering
Disposal
ENVIRONMENT:
Atmosphere
Lithosphere
Hydrosphere
Disposal
Recovery Processes
Resources Extraction
Production
Solid Waste at Transfer Station
Transport
Mineral & Agricultural Solid Waste
Disposal
Disposal
Disposal
Recovery Processes

Figure 1 Solid Waste Management System

②

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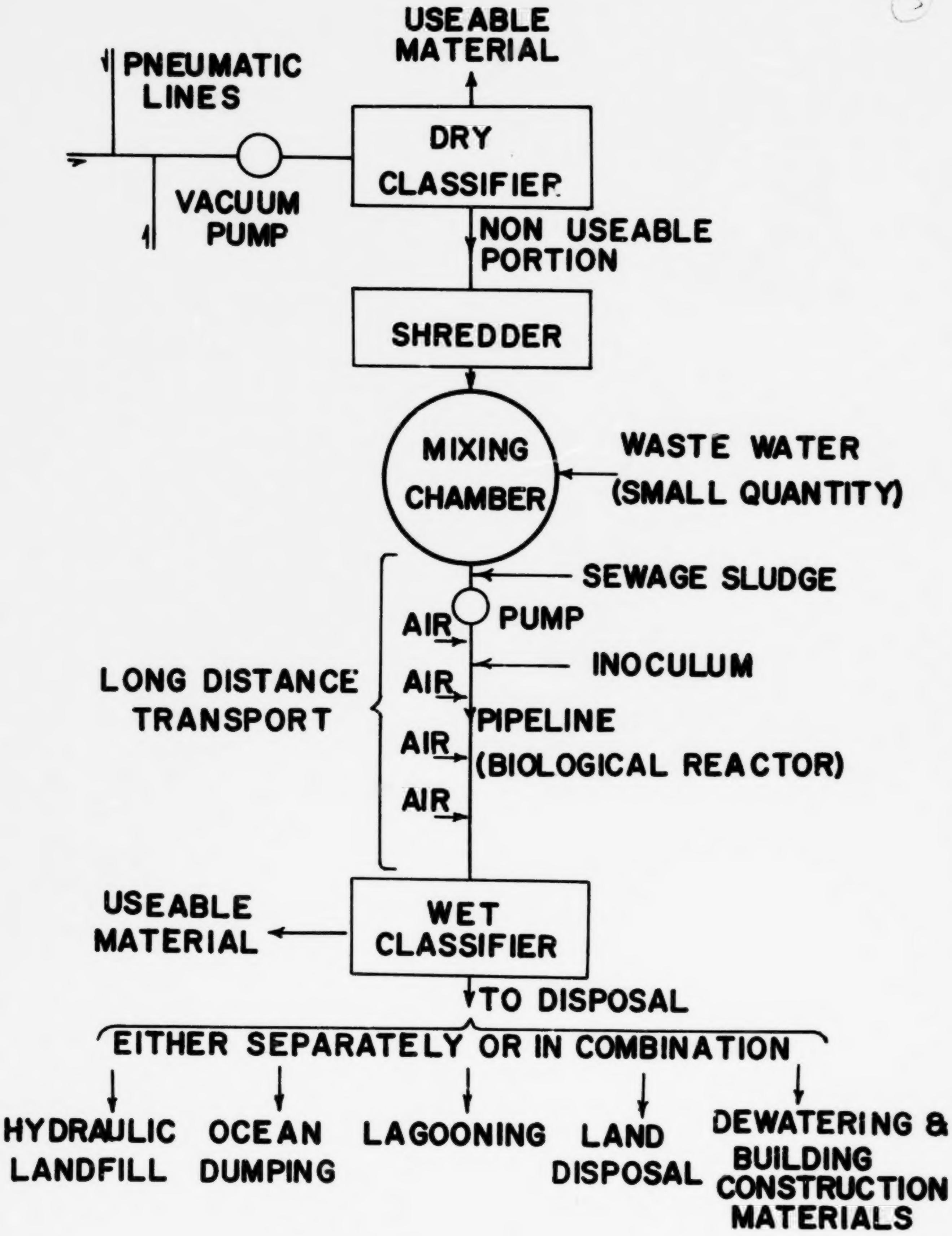
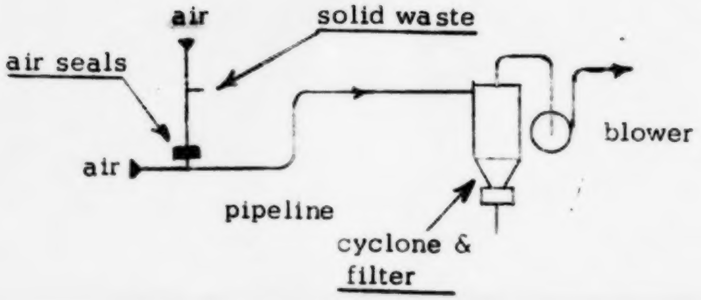
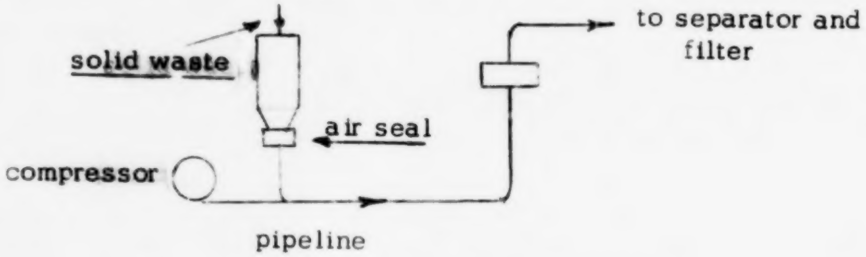
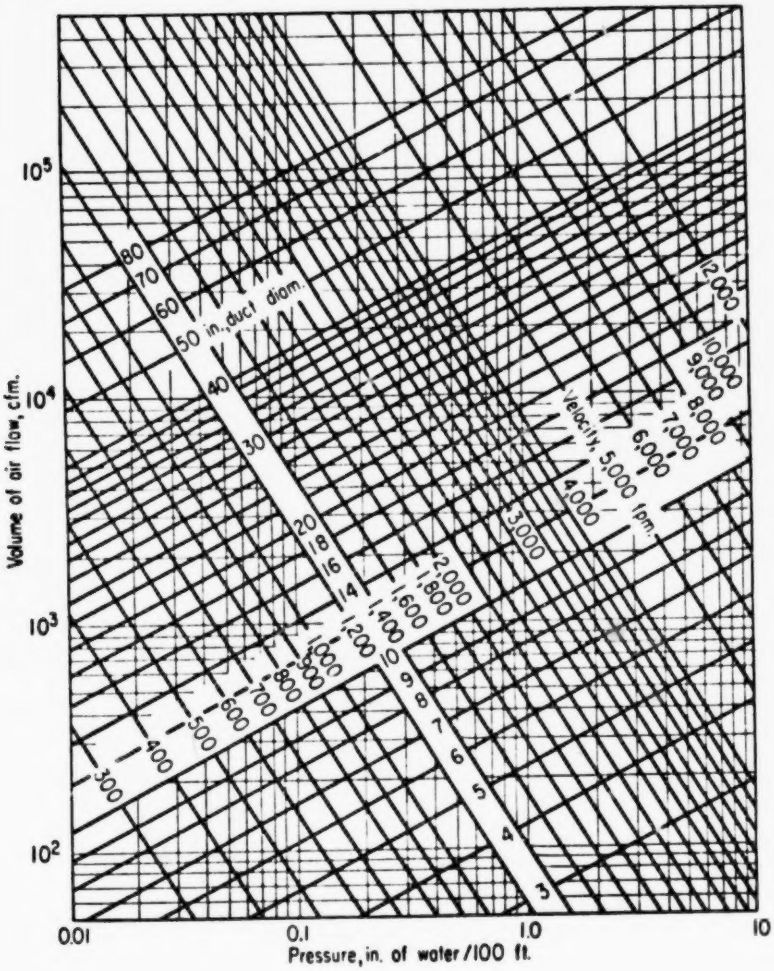

USEABLE MATERIAL
PNEUMATIC LINES
DRY CLASSIFIER
VACUUM PUMP
NON USEABLE PORTION
SHREDDER
MIXING CHAMBER
WASTE WATER (SMALL QUANTITY)
SEWAGE SLUDGE
PUMP
AIR
INOCULUM
AIR
LONG DISTANCE TRANSPORT
PIPELINE (BIOLOGICAL REACTOR)
AIR
AIR
USEABLE MATERIAL
WET CLASSIFIER
TO DISPOSAL
EITHER SEPARATELY OR IN COMBINATION
HYDRAULIC LANDFILL
OCEAN DUMPING
LAGOONING
LAND DISPOSAL
DEWATERING & BUILDING CONSTRUCTION MATERIALS


air
solid waste
air seals
air
pipeline
cyclone & filter
blower

3a- vacuum conveying system


solid waste
to separator and filter
air seal
compressor
pipeline

3b- positive pressure conveying system



Taken from

Fischer, J., "practical Pneumatic Conveyor Design", Chemical Engineering, pp 114-118, June 2, 1958

⑦

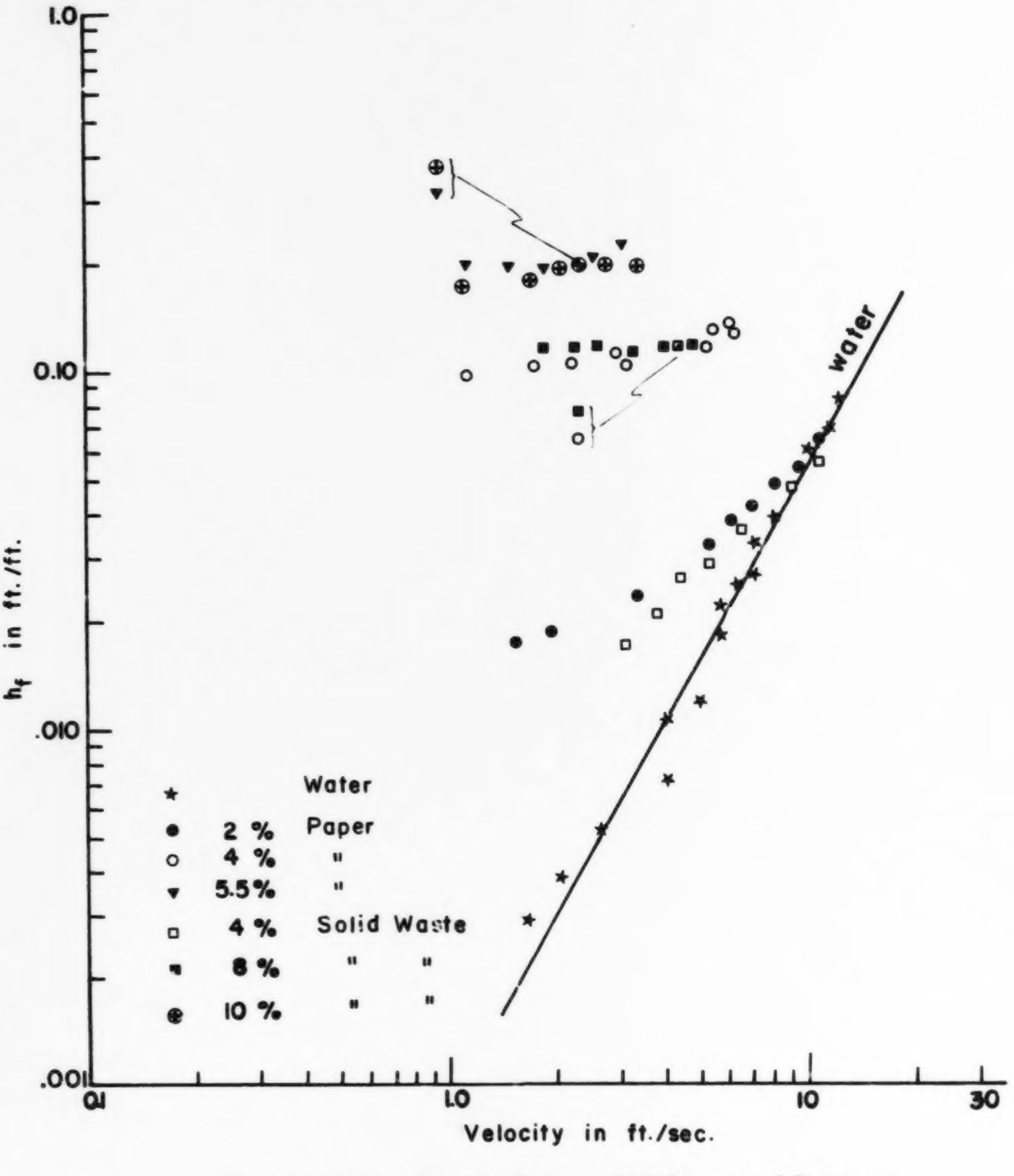


Fig. 10- Solid Waste Slurry (55% paper) Behavs like Its Paper Component, 6" pipe.

(8)

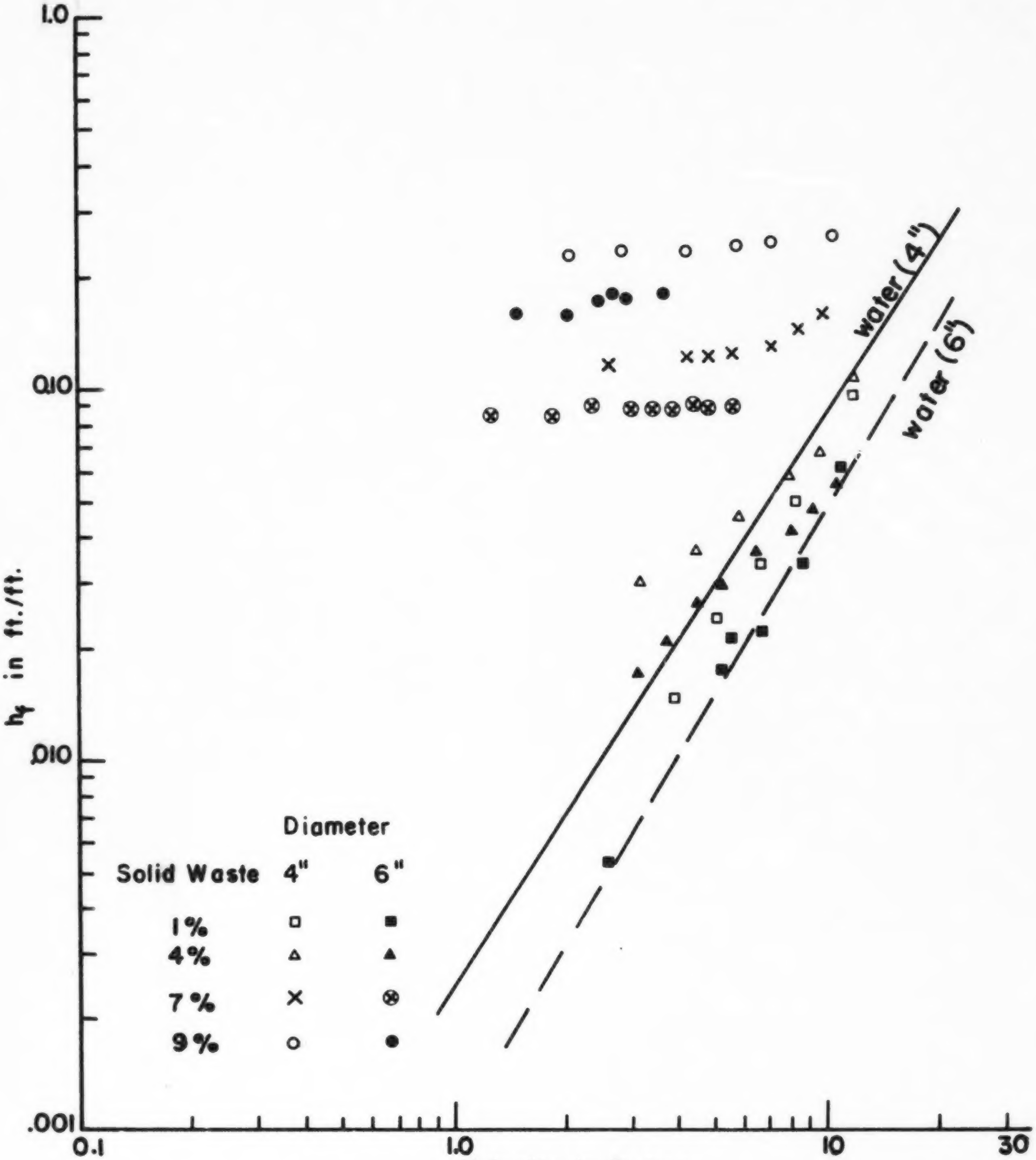


Fig. 6- Diameter Effect, 6" & 4" pipe.

(9)

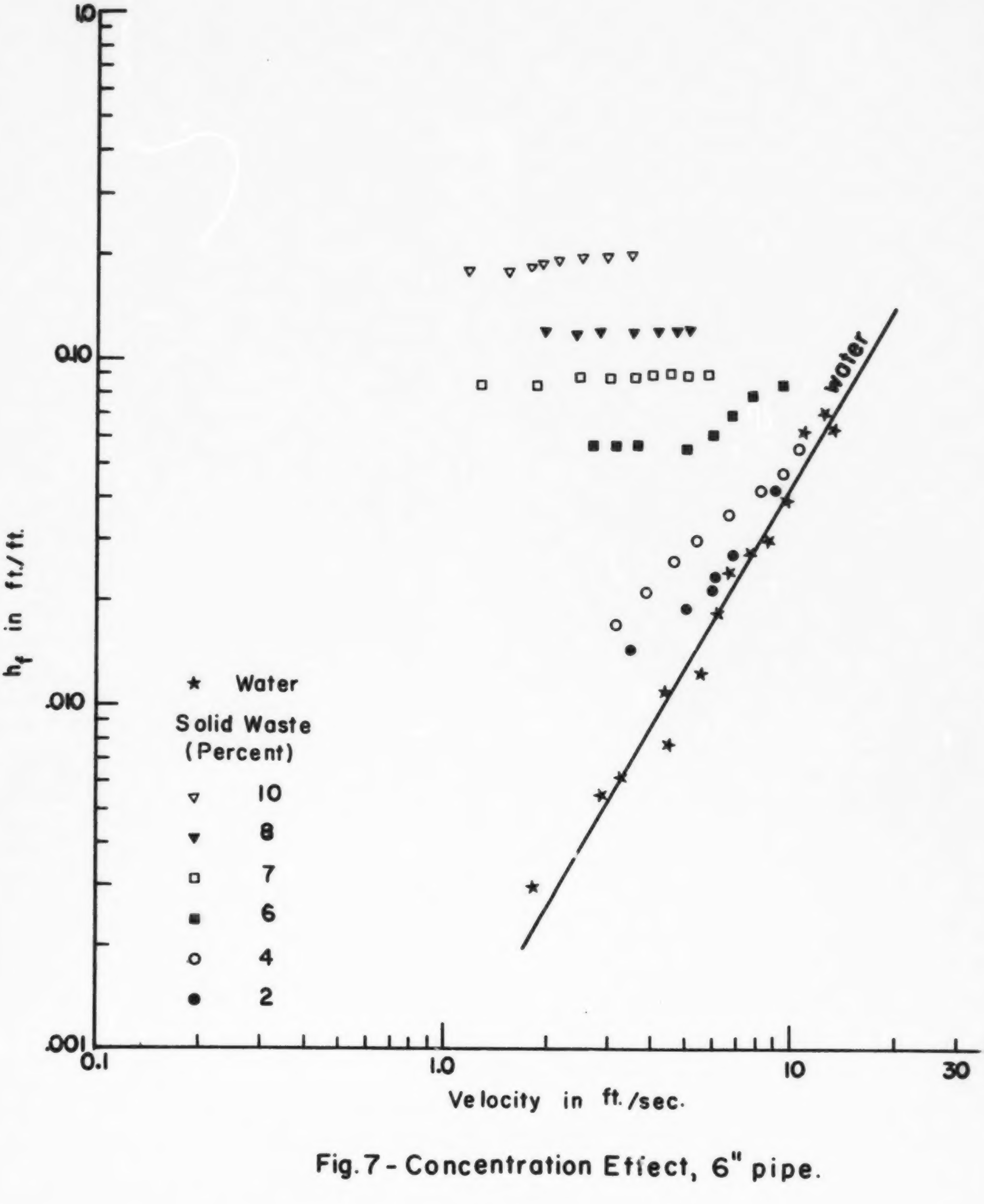


Fig. 7 - Concentration Effect, 6" pipe.

(10)

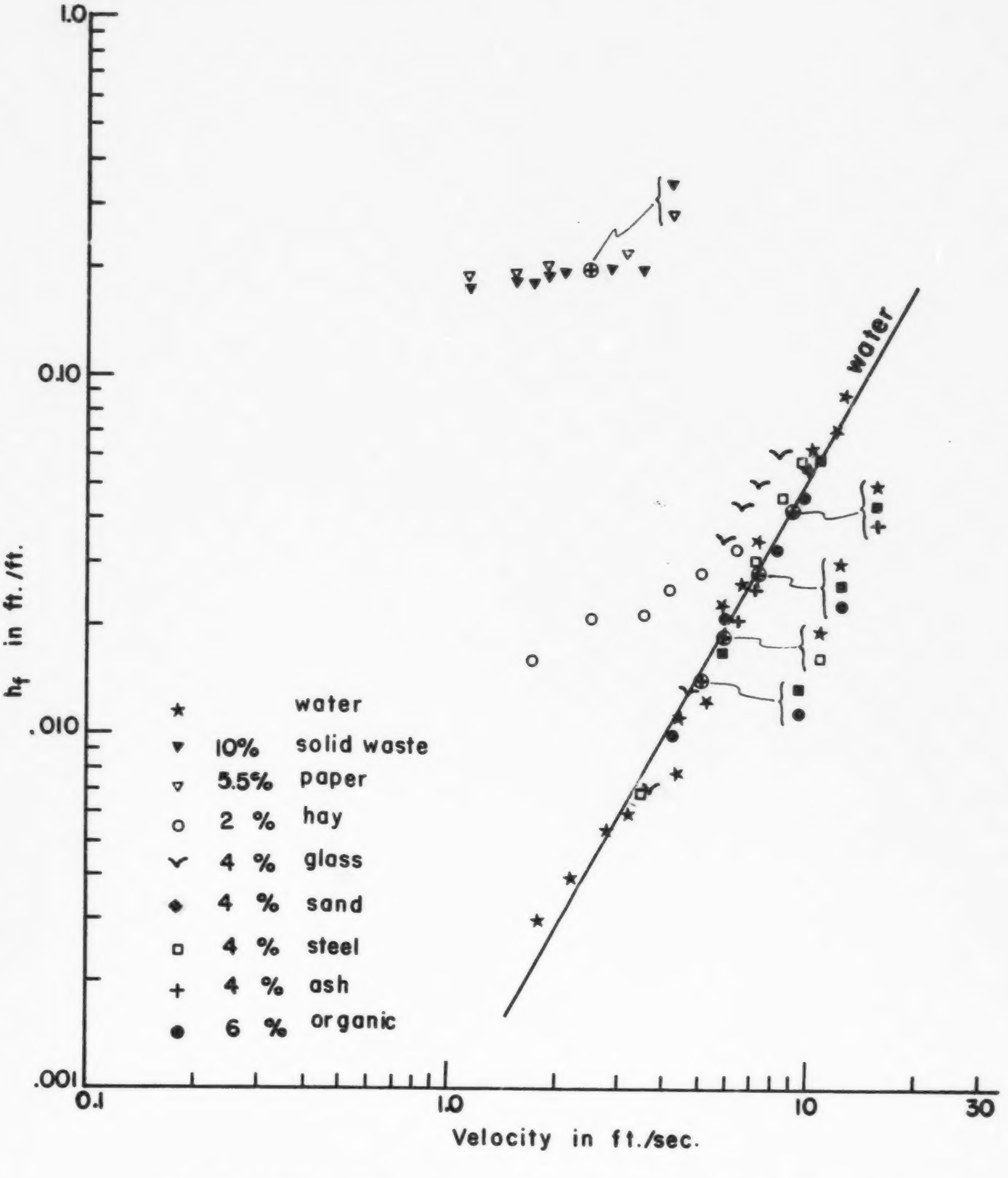
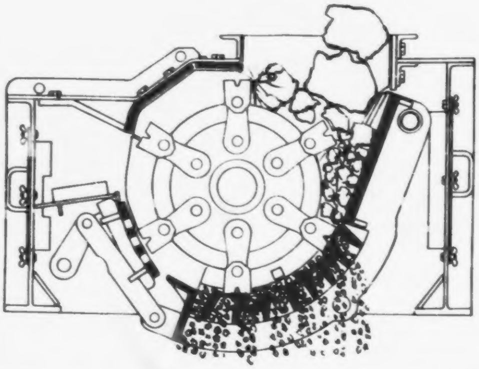
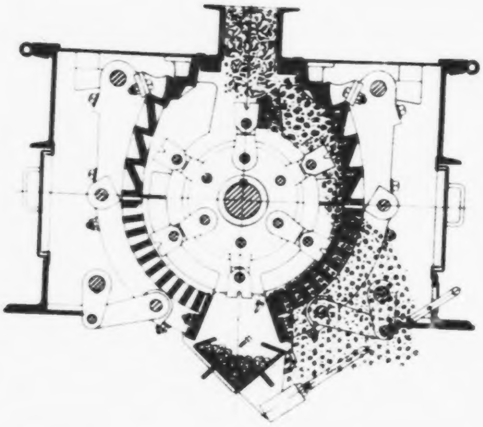


Fig. 8 - Major Components of Solid Waste & Average Mix, 6" pipe.

11



This illustration shows how material must remain in hammermill grate bar chamber until crushed small enough to pass bar openings. The reduction in this mill is mostly by attrition.



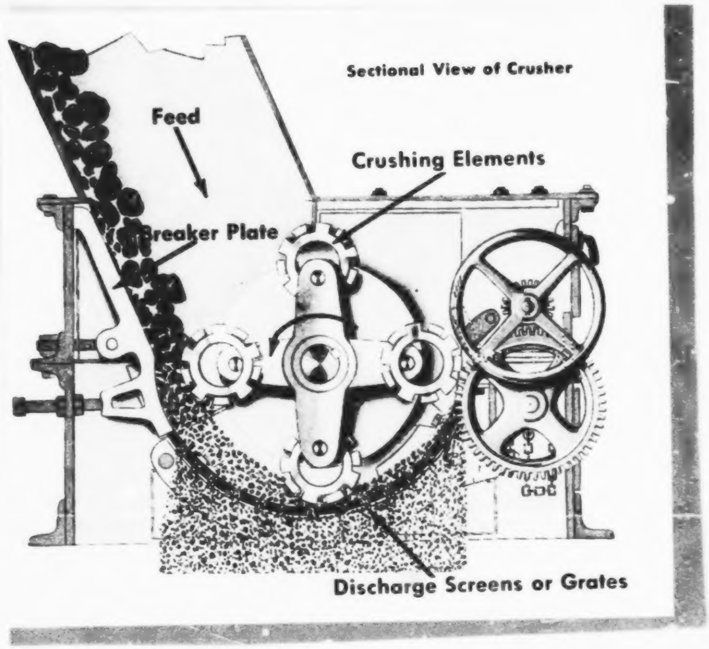
Reversible hammermill. Note size reduction by free air impact. As material enters hammer path the reduced material is swept through screen bars in lower part of crushing zone. This machine has all the advantages of hammermill crushing plus a minimum of wear on parts.

Taken from

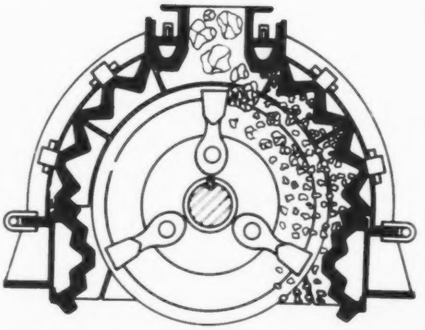
Pennsylvania
Crusher Division
West chester, Pa.

Taken from

American
Pulverizer Co.
1249 Mackland Ave.
Saint Louis, 10, MO.


Sectional View of Crusher
Feed
Crushing Elements
Breaker Plate
Discharge Screens or Grates

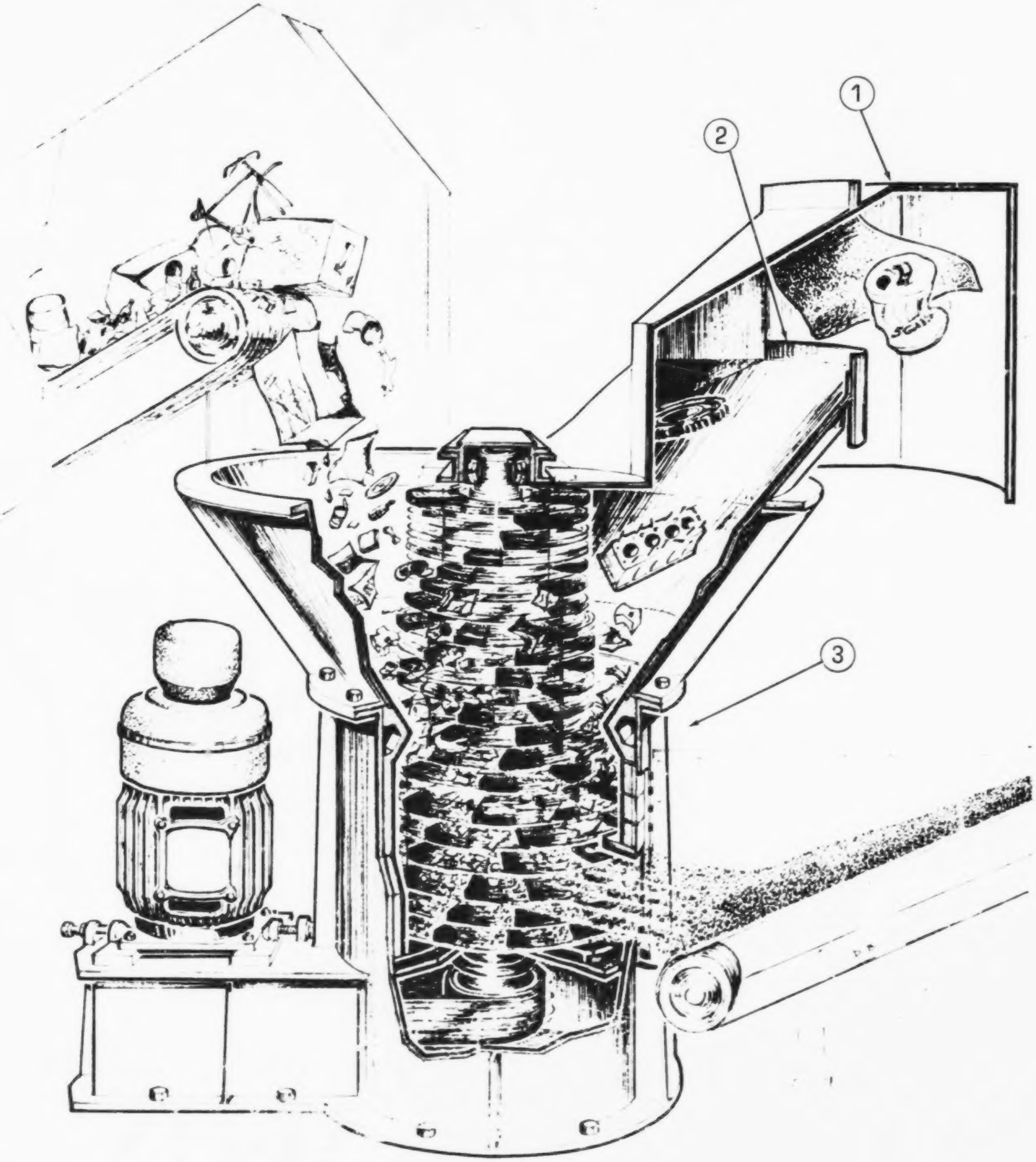
Pennsylvania
Crusher Div.
West Chester, Pa.



Reduction by impact only is well illustrated by the Pennsylvania Reversible Impactor.

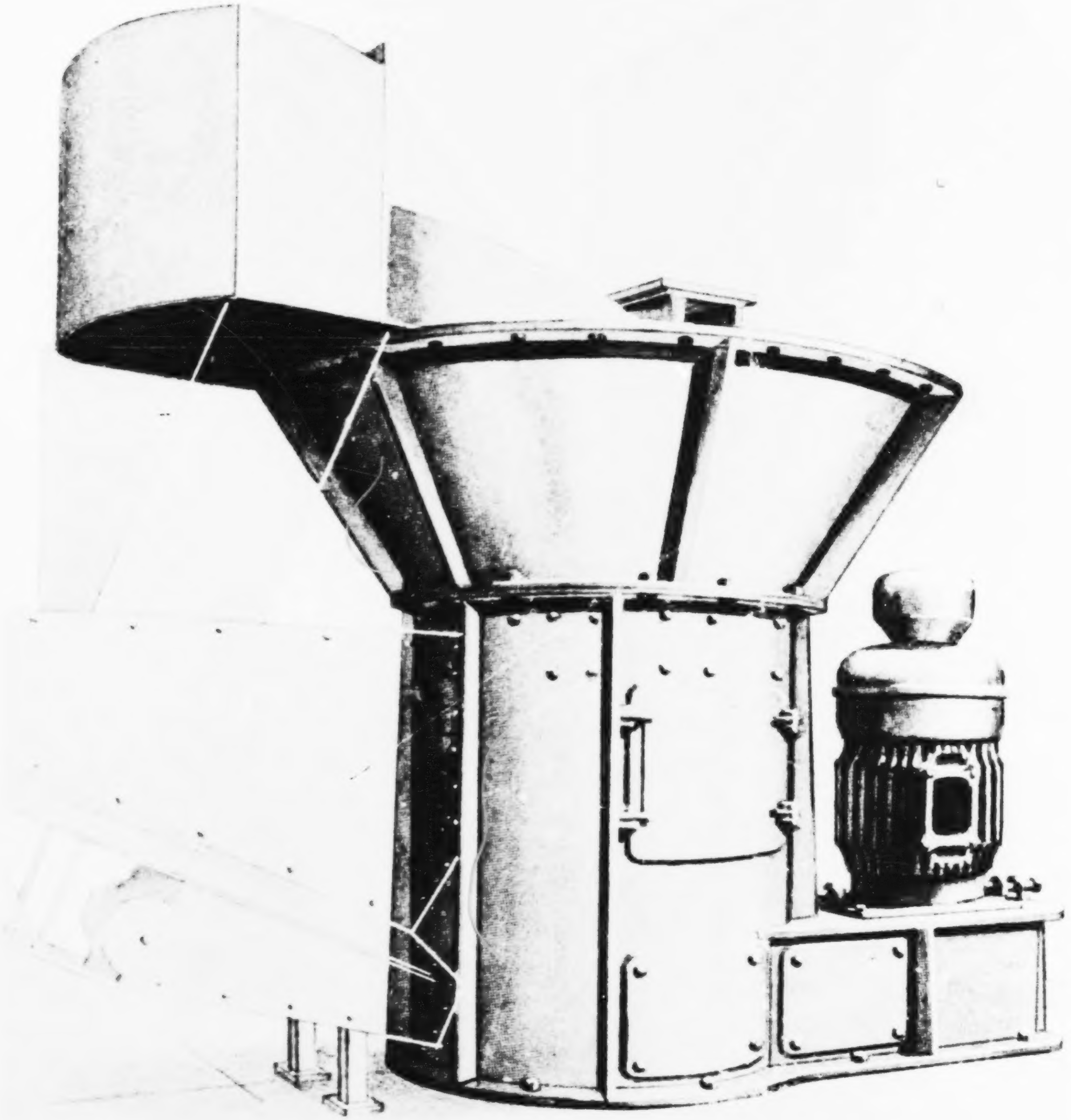
Taken from The Heil Co.
3000 West Montana st. Milwaukee, Wisconsin 53201

(13)



1. Rejects chute. 2. Adjustable rejects control plate.
3. Adjustable grinding depth plates and retention lip (inside machine).

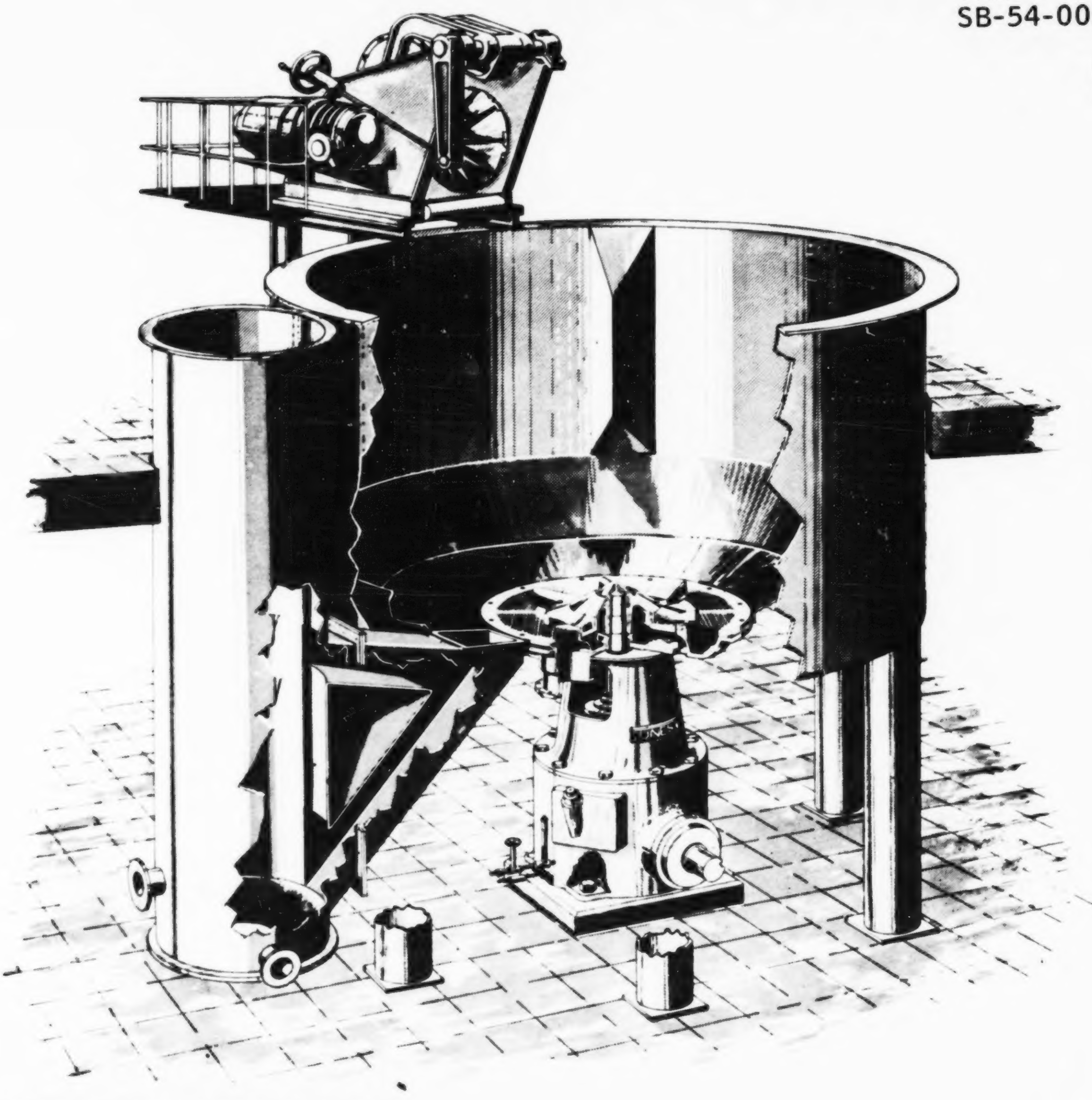
THE TOLLEMACHE* VERTICAL SHAFT BALLISTIC SORTER PULVERIZER



THE HEIL CO. MILWAUKEE, WISCONSIN, HAS EXCLUSIVE SELLING AND MANUFACTURING RIGHTS FOR THIS EQUIPMENT IN THE UNITED STATES

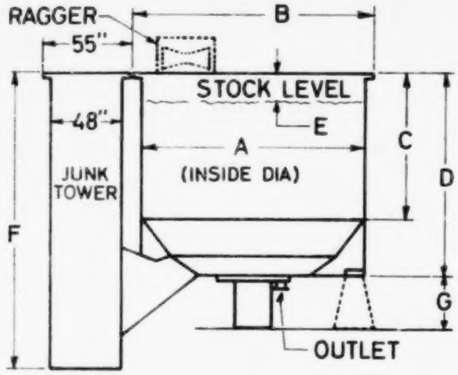
BULLETIN
SB-54-005 C

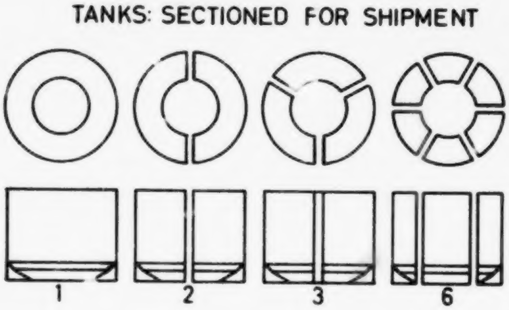
17



JONES SHARK CONTINUOUS WASTE PULPER

JONES SHARK
CONTINUOUS WASTE PULPER


RAGGER
B
55"
STOCK LEVEL
48"
E
A
(INSIDE DIA)
C
D
JUNK
TOWER
F
G
OUTLET


TANKS: SECTIONED FOR SHIPMENT
1
2
3
6

GENERAL DIMENSIONS

(not to be used for construction)

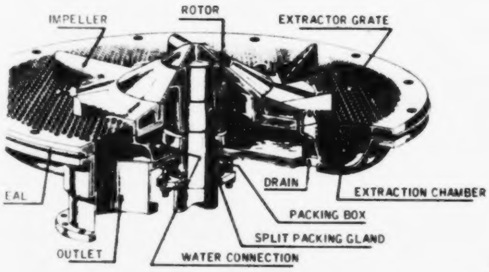
Model No.		3404	3405	3408	3410	3415	3420	3430	3440	3460	3480
Capacity at Operating level	(cu. ft.)	100	135	220	275	405	540	810	1080	1620	2160
	(lbs @ 4%)	250	340	550	700	1000	1350	2000	2700	4000	5400
Nominal hp		50-60	50-75	75-100	75-125	125-150	125-200	200-250	200-300	300-400	300-500
Rotor dia. *		22	22	28	28	35	35	44	44	55	55
A*		84	92	106	116	132	146	168	184	212	232
B*		93	101	115	125	141	155	179	195	222	243
C*		54	58	61	62	72	75	80	85	92	98
D*	(outside hgt.)	67	72	82	84	98	104	113	121	132	143
E*		30	30	30	30	36	36	36	36	36	36
F*		125	135	150	159	176	190	203	223	240	264
G*	V-Belt drive	69	69	69	69	69	69	-	-	-	-
	Integral motor	-	-	69	74	75	80	80	81	87	92
	Integral gear	56	56	56	56	56	56	57	57	65	65
Outlet diameter*		8	8	10	10	12	12	16	16	16	16
Weight lbs	Shipping	7500	8300	9000	9800	12300	14800	18100	22000	27500	41500
	Flooded	19800	23900	32300	38400	55400	70300	97300	123900	174000	231200
Tank sections for ship.		1	1	1	1	2	2	2	3	6	6

*Values are in inches

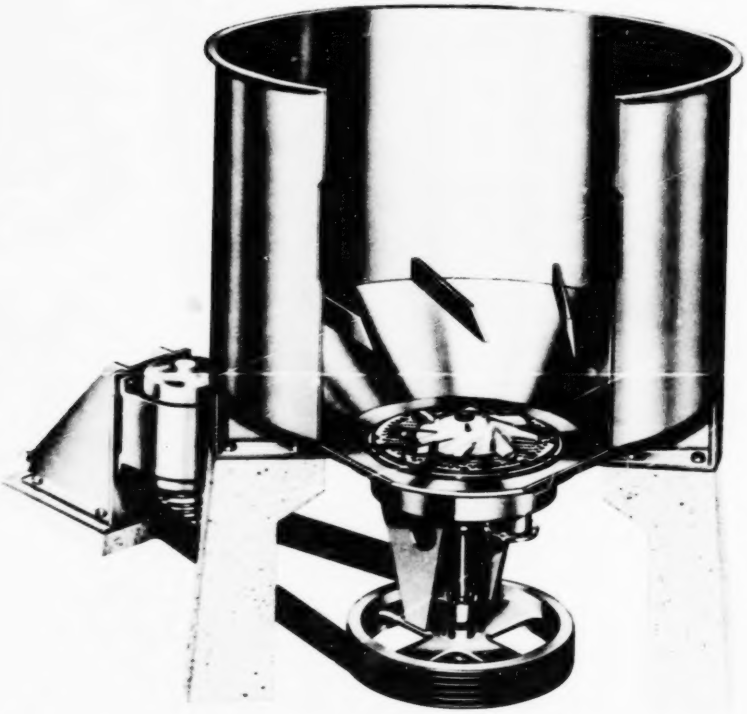
SPECIFICATIONS

Each unit is complete as specified below with tank, legs and junk opening.

MATERIAL TYPE		IRON WEAR RESISTANT (IWR)	CORROSION RESISTANT (CRE)	SUPER CORROSION RESISTANT (S-CRE)
Tank		Cor-Ten Steel	304 S/S	316 S/S
Main Rotor		Ductile Iron	410 S/S	316 S/S
Impeller		410 S/S	410 S/S	17-4 pH S/S
Extractor Grate		410 S/S	410 S/S	17-4 pH S/S
		Ductile Iron	304 S/S	316 S/S

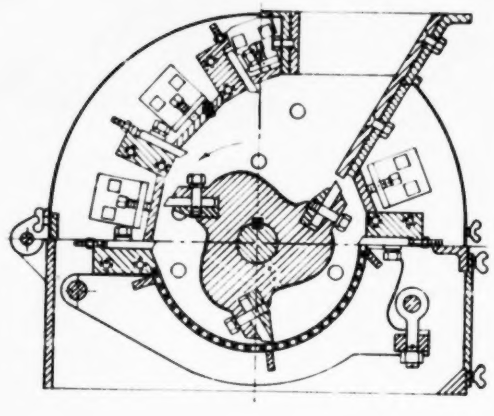

IMPELLER
ROTOR
EXTRACTOR GRATE
EAL
DRAIN
EXTRACTION CHAMBER
PACKING BOX
SPLIT PACKING GLAND
OUTLET
WATER CONNECTION

For mills that do not require heavy duty HV or HR units, Black Clawson builds the medium duty HCV.



Taken from: Black Clawson
Shartle Division
Middletown, Ohio 45042

From: American
pulverizer Co.
1249 Macklind Ave.
St. Louis 10, MO.



Taken from:
The Young
Machinery
Company, Inc.
Muncy, Pennsylvania
17756

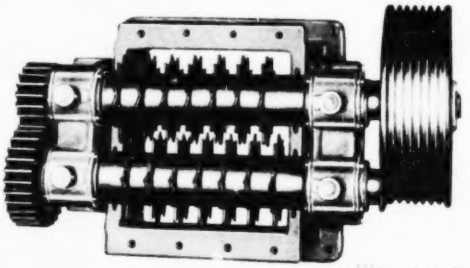
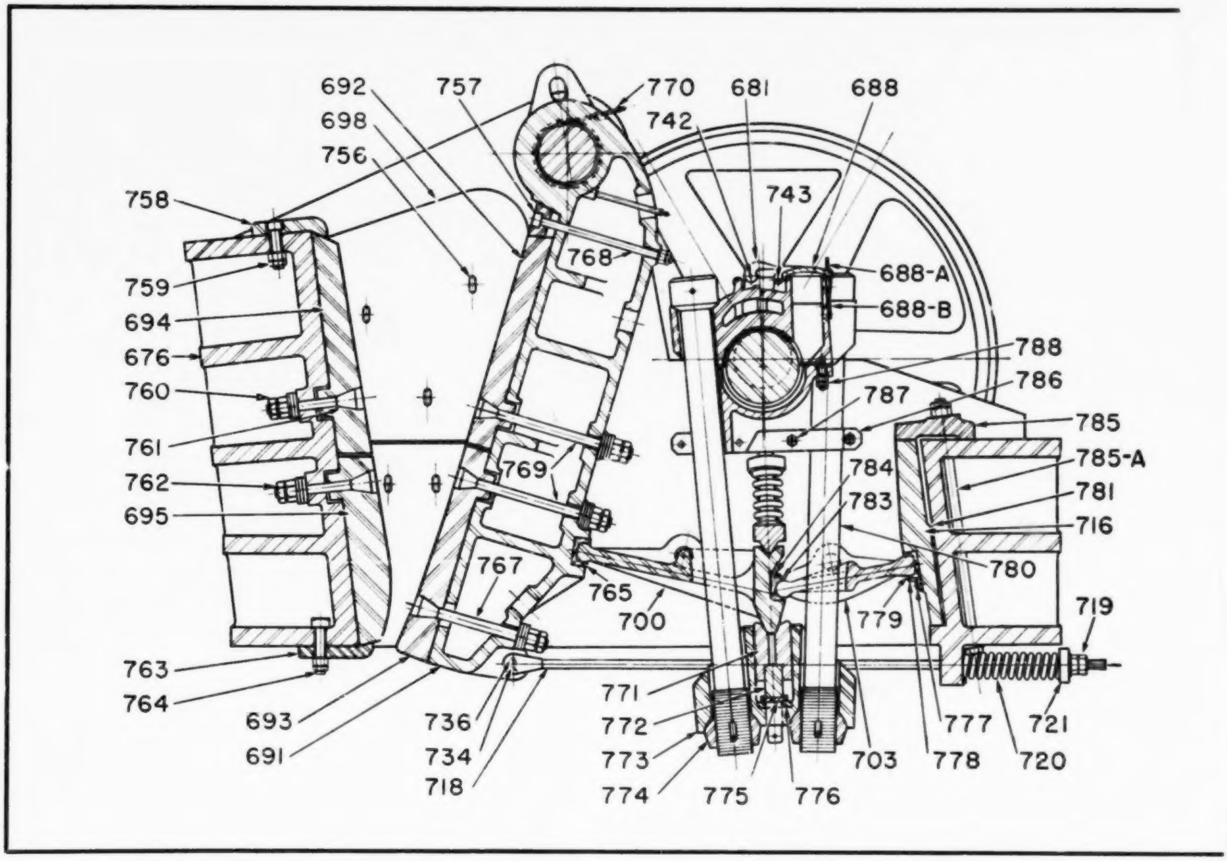


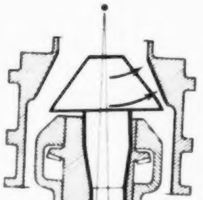
FIG. 148 D
Coarse crushing arrangement of
[illegible] for reducing wood charcoal


692
757
770
681
688
698
742
756
743
758
768
688-A
759
688-B
694
676
788
786
760
787
785
761
784
785-A
762
769
781
695
783
716
780
767
765
700
779
719
763
764
693
691
736
734
718
771
772
773
774
775
776
703
777
778
721
720

Taken from

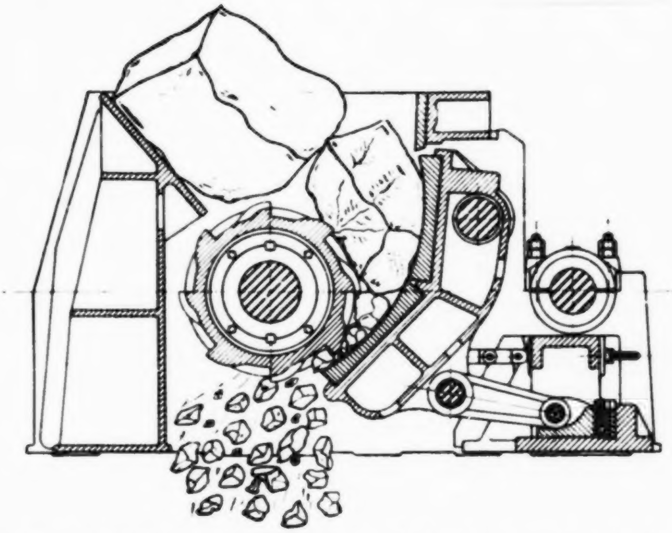
Taylor Engineering & Manufacturing Co.

Allentown, Pa.



From

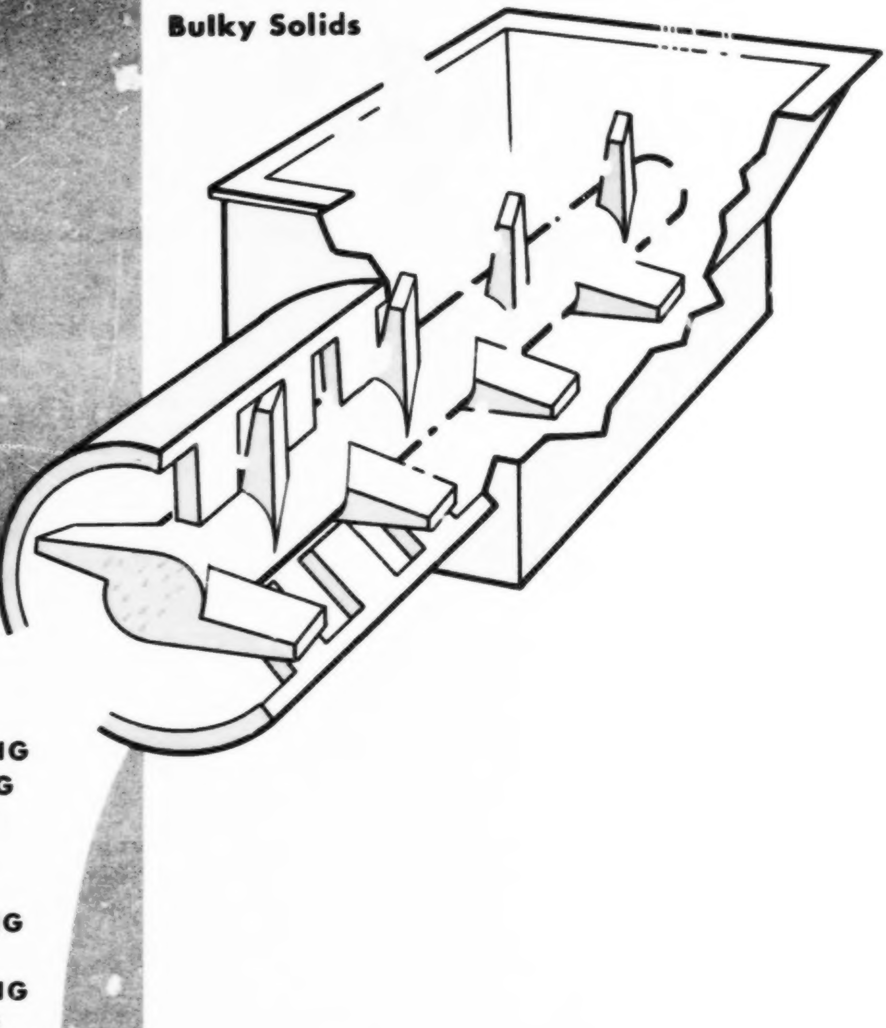
Pennsylvania
Crusher Division
West chester, Pa



The single roll crushes by shear and compression. An ideal primary crusher for friable materials even when wet and sticky. Requires low head room.

From

Pennsylvania Crusher Division
West chester, Pa.



HOGGING
CRUSHING
BREAKING
CHOPPING
SHREDDING
PASTE MIXING
BLENDING
DOUGH MIXING
GRANULATING
PELLETING

BULLETIN PBRE-1

Equipment for the Process Industries
Size Reduction • Mixing • Heat Exchange

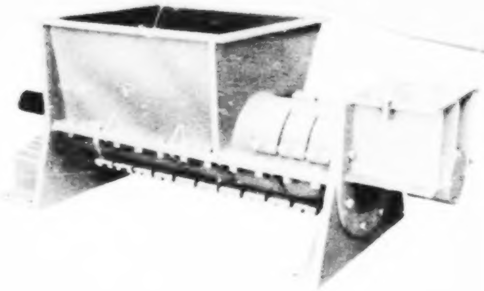
Rietz
MANUFACTURING COMPANY

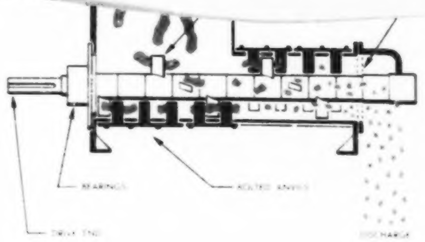
Santa Rosa, California • West Chester, Pennsylvania
Sales and Engineering Offices in Principal Cities

PB SERIES

INDUSTRIAL DESIGN

Prebreakers for Heavy Duty Crushing Applications

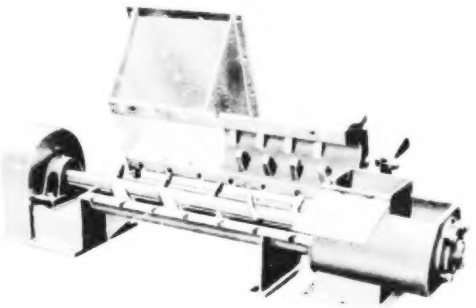


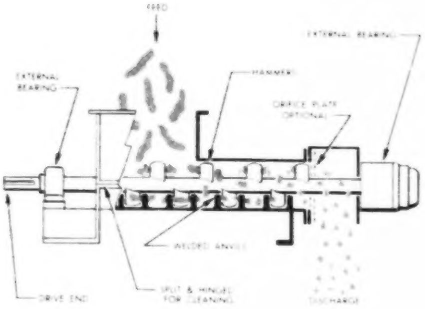

BEARINGS
BOLTED ANVILS
DRIVE END
DISCHARGE

PB SERIES

SANITARY DESIGN

Prebreakers for Ease of Cleaning in Food and Chemical Industries

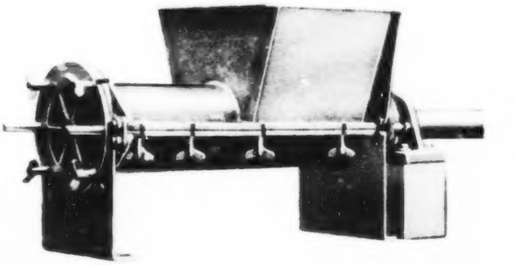


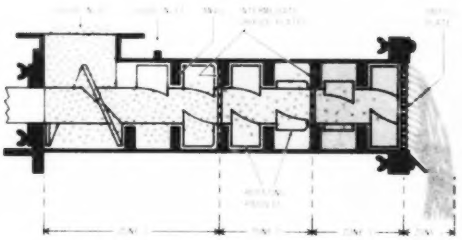

FEED
EXTERNAL BEARING
EXTERNAL BEARING
HAMMERS
ORIFICE PLATE OPTIONAL
WELDED ANVILS
DRIVE END
SPLIT & HINGED FOR CLEANING
DISCHARGE

RE SERIES

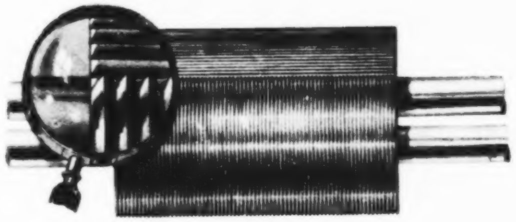
RIETZ EXTRUCTOR

With Orifice Plate for Continuous Mixing and Extrusion Applications



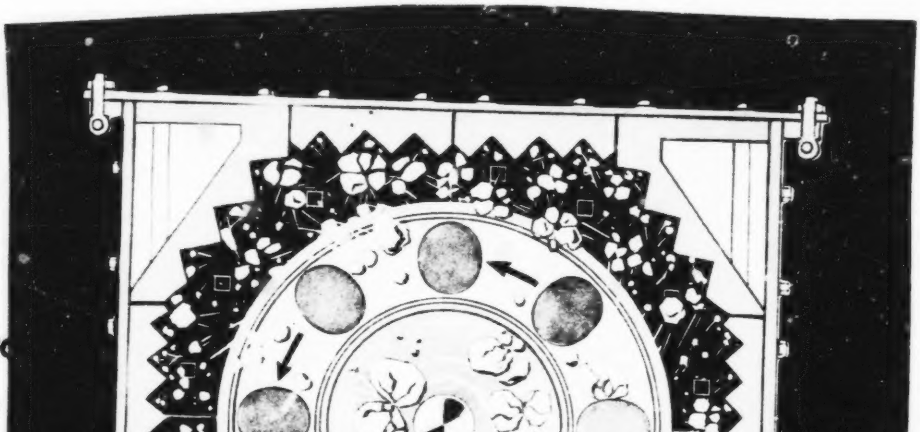


Rietz MANUFACTURING COMPANY • San



Taken from :

Sprout _ Waldron
Manufacturing Engineers
Muncy, Pennsylvania, U.S.A



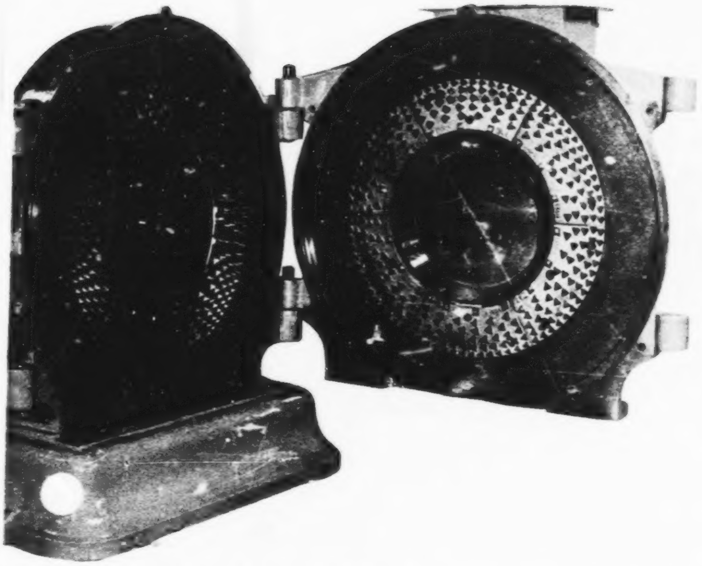
From :

Stedman
Foundary & Machine Co. Inc
Aurora, Indiana

From:

Sprout-Waldron
Manufacturing
Engineers

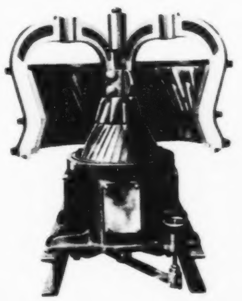
Muncy, Pa.



The shell holding the stationary plate swings open easily and quickly for cleaning and plate changes, and all parts of the mill are readily accessible.

From

Sturtevant Mill Co.
~~[illegible]~~
103 Clayton Street
Boston, Massachusetts
02122



From:

National Engineering Co.
Process Equipment Div
638 Machinery Hall
Chicago Ill. 60606

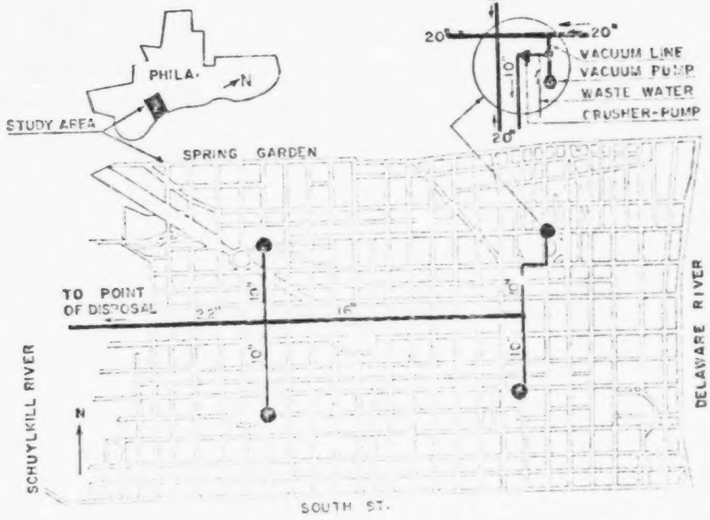
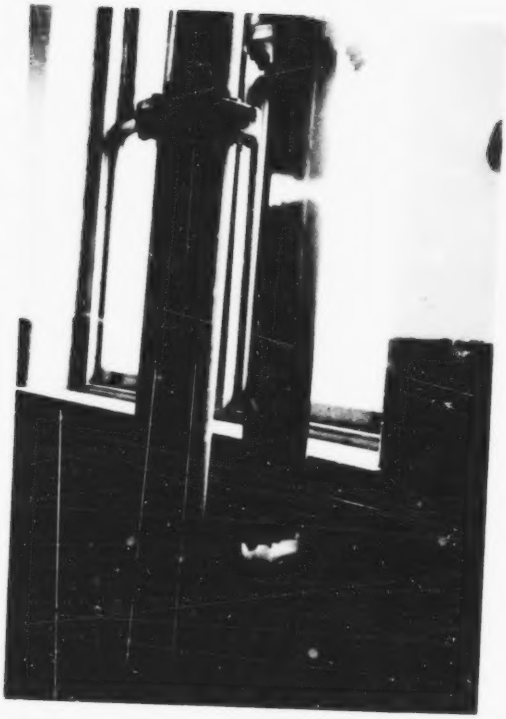
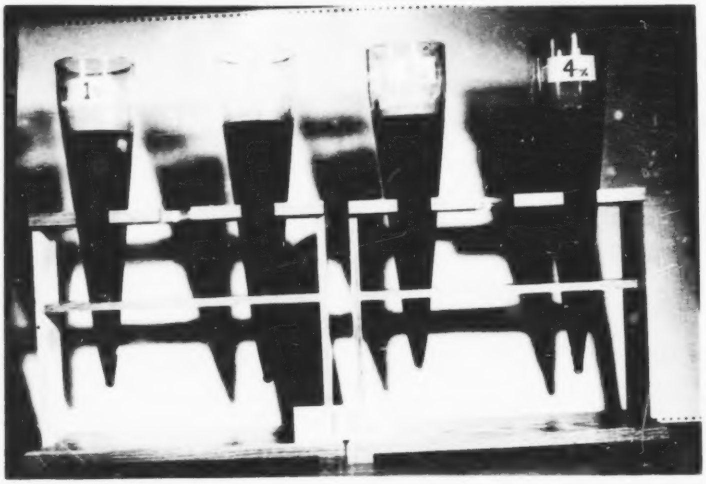
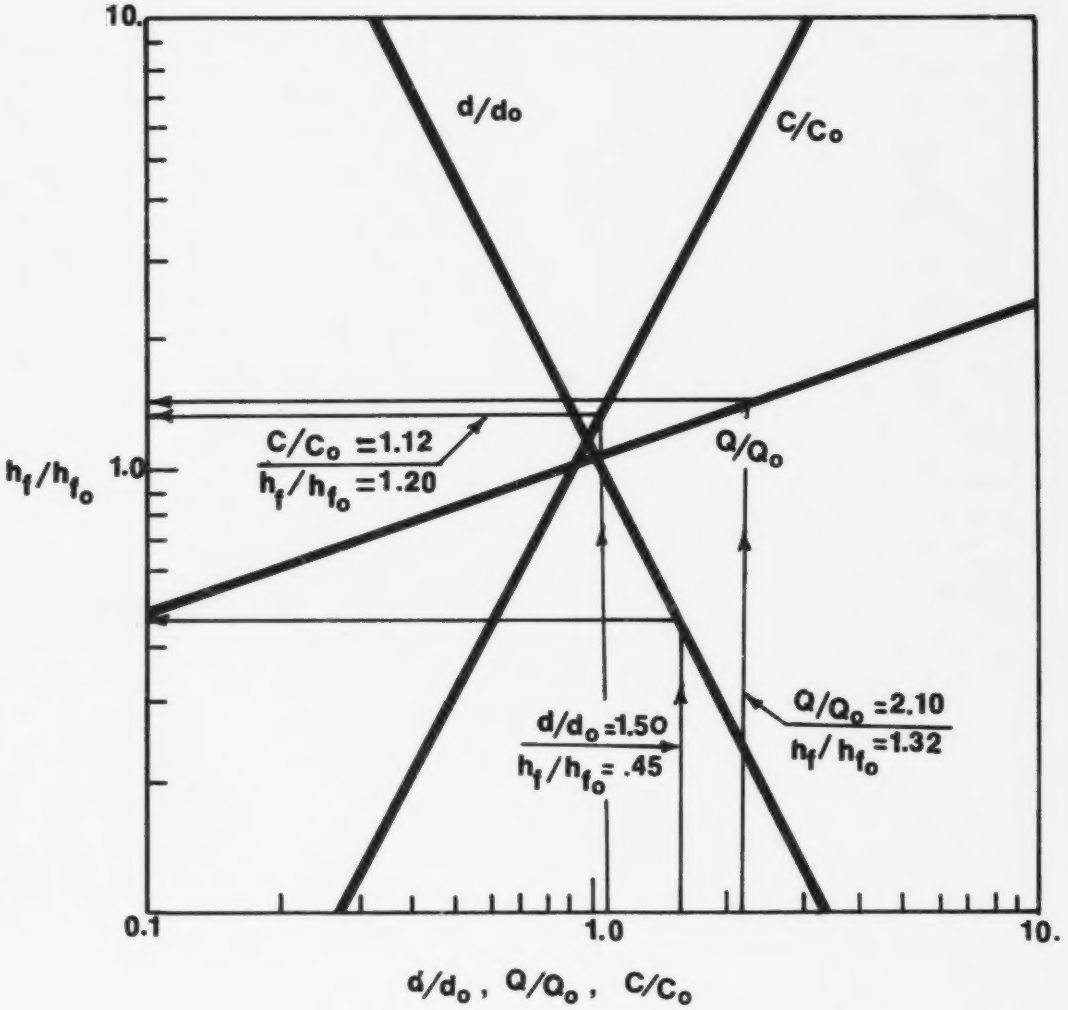

20"
20"
20"
VACUUM LINE
VACUUM PUMP
WASTE WATER
CRUSHER-PUMP
10"
20"
PHILA.
N
STUDY AREA
SPRING GARDEN
TO POINT OF DISPOSAL
22"
16"
10"
10"
10"
10"
SCHUYLKILL RIVER
DELAWARE RIVER
N
SOUTH ST.

Figure 1. Study Area, Pneumo-Slurry System (Pneumatic pipelines are not shown. There are 20" vacuum lines in all streets.)




1
4%


10.
1.0
0.1
1.0
10.
h_f/h_{f_o}
d/d_o, Q/Q_o, C/C_o
d/do
C/Co
Q/Q_o
$C/C_o = 1.12$
$h_f/h_{f_o} = 1.20$
$d/d_o = 1.50$
$h_f/h_{f_o} = .45$
$Q/Q_o = 2.10$
$h_f/h_{f_o} = 1.32$